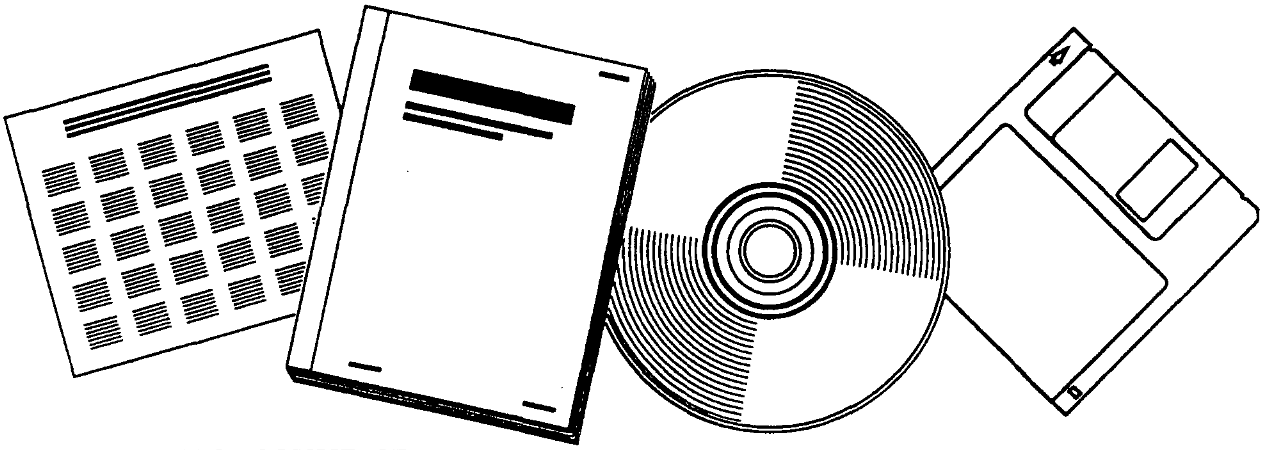
PB97-152292

NTIS®
Information is our business.

CAPABILITIES OF ATOMIC WEAPONS SANITIZED VERSION

ARMED FORCES SPECIAL WEAPONS PROJECT
WASHINGTON, DC

NOVEMBER 1957



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

Donohoe Firm

LIBRARY REFERENCE COPY

~~CONFIDENTIAL~~

DEPARTMENT OF THE ARMY TECHNICAL MANUAL — **TM 23-200** SAN
DEPARTMENT OF THE NAVY — **OPNAV INSTRUCTION 03400.1B** SAN
DEPARTMENT OF THE AIR FORCE — **AFL 136-1** SAN
MARINE CORPS PUBLICATIONS — **NAVMC 1104 REV** SAN

LOG # BDM/W- 0751-83-C
COPY # 1

PB97-152292

CAPABILITIES OF [redacted] ATOMIC WEAPONS ([redacted])

sanitized version

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

Prepared by
Armed Forces Special Weapons Project

REGRADING DATA CANNOT BE PREDETERMINED

DNA TECHNICAL LIBRARY REFERENCE COPY

DECLASSIFIED WITH DELETIONS
DSWA OPSSI/FOIA 93-090
DISTRIBUTION STATEMENT A
APPLIES TO THIS VERSION ONLY
DATE 26 Nov 97

DEPARTMENTS OF THE ARMY, THE NAVY AND THE AIR FORCE

REVISED EDITION NOVEMBER 1957

~~CONFIDENTIAL~~

PORTIONS OF DOCUMENT RELEASED UNDER THE
FREEDOM OF INFORMATION ACT
DSWA CASE NO. 93-090

1884

PB97-152292

~~CONFIDENTIAL~~

TM 23-200/OPNAV INSTRUCTION 03400.1B/AFL 136-1/NAVMC 1104 REV

THIS PUBLICATION SUPERSEDES TM 23-200, OPNAV INSTRUCTION 003400.1A, AFL 136-4/NAVMC 1104, 1 JUNE 1955, INCLUDING C 1, 1 APRIL 1956, C 2, 17 OCTOBER 1956, AND C 3, 19 SEPTEMBER 1957

CAPABILITIES
OF
ATOMIC WEAPONS (U)

UNITED STATES OF AMERICA WAR OFFICE

NAVY DEPARTMENT UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY UNITED STATES MARINE CORPS

United States Government Printing Office
Washington : 1957

~~CONFIDENTIAL~~

Department of the Army Technical Manual
Department of the Navy
Department of the Air Force Manual
Marine Corps Publications

C 1, TM 23-200
OPNAV Instruction 03400.1B, CH-1
AFM 136-1A
NAVMC 1104 REV, CH-1

Capabilities of Atomic Weapons (U)

CHANGES
No. 1

DEPARTMENTS OF THE ARMY, THE NAVY,
AND THE AIR FORCE
WASHINGTON 25, D.C., *24 June 1960*

TM 23-200/OPNAV Instruction 03400.1B/AFM 136-1/NAVMC 1104 REV, 29 November 1957, is changed as follows:

1. Change the Air Force number to read: **AFM 136-1.**
2. Remove pages v and vi and substitute pages v and vi of Changes Number One.
3. Remove pages xv through xxii and substitute pages xv through xxii of Changes Number One.
4. Remove pages 2–15 through 2–18 and substitute pages 2–15 through 2–18 of Changes Number One.
5. Remove pages 4–1 through 4–8 and substitute pages 4–1 through 4–8 of Changes Number One.
6. Following page 4–16, add pages 4–16a through 4–16d of Changes Number One.
7. Remove pages 4–21 through 4–24 and substitute pages 4–21, 4–22, 4–22a through 4–22d, 4–23, and 4–24 of Changes Number One.
8. Remove pages 9–3 and 9–4 and substitute pages 9–3 and 9–4 of Changes Number One.
9. Remove pages 9–9 through 9–12 and substitute pages 9–9 through 9–12 of Changes Number One.
10. Remove pages I–7 and I–8 and substitute pages I–7 and I–8 of Changes Number One.
11. Remove pages I–29 through I–32 and substitute pages I–29 through I–32 of Changes Number One.
12. Remove pages II–3 and II–4 and substitute pages II–3 and II–4 of Changes Number One.
13. Remove pages 1, 2, 5 through 8, and 11 and substitute pages 1, 2, 5 through 8, 11 and 12 of Changes Number One.

CONTENTS

PART ONE. PHYSICAL PHENOMENA

SECTION I. INTRODUCTION

Page
1.1 Explosion of a Nuclear Weapon 1-1
  a. General 1-1
  b. Energy partition 1-1
1.2 Weapon Ratings 1-1
1.3 Data Presentation 1-2
1.4 Types of Burst 1-2
  a. General 1-2
  b. Brief description of an air burst 1-2
    (1) Definition 1-2
    (2) Development 1-3
    (3) Blast wave 1-4
    (4) Thermal radiation 1-5
    (5) Nuclear radiation 1-5
    (6) Cloud 1-5
  c. Brief description of a surface burst 1-5
    (1) Definition 1-5
    (2) Development and air blast wave 1-5
    (3) Ground shock 1-5
    (4) Crater 1-6
    (5) Thermal radiation 1-6
    (6) Nuclear radiation 1-6
      (a) Initial 1-6
      (b) Residual 1-7
    (7) Cloud 1-7
    (8) Surface bursts on water 1-7
  d. Brief description of a burst in the transition zone between an air burst and a surface burst 1-7
    (1) General 1-7
    (2) Development 1-7
    (3) Blast wave, thermal and nuclear radiation 1-7
    (4) Ground shock and crater formation 1-8
  e. Brief description of an underground burst 1-8
    (1) Definition 1-8
    (2) Development 1-8
    (3) Air blast 1-8
    (4) Column, cloud and base surge 1-8
    (5) Ground shock 1-9
    (6) Crater 1-9
    (7) Thermal radiation 1-9
    (8) Nuclear radiation 1-9
      (a) Initial 1-9
      (b) Residual 1-9
  f. Brief description of an underwater burst 1-10
    (1) Definition 1-10
    (2) Development and gas bubble 1-10
    (3) Water shock 1-11
    (4) Air blast 1-12
    (5) Surface effects 1-12
    (6) Thermal and nuclear radiation 1-12

PART ONE. PHYSICAL PHENOMENA—Continued

SECTION II. BLAST AND SHOCK PHENOMENA

Page

- 2.1 Air Blast Phenomena 2–1
  - *a.* General 2–1
  - *b.* Propagation in free air 2–2
    - (1) General 2–2
    - (2) Time of arrival 2–2
    - (3) Overpressure 2–2
      - (*a*) Peak overpressure 2–2
      - (*b*) Duration 2–2
      - (*c*) Impulse and wave forms 2–2
    - (4) Dynamic pressure 2–2
      - (*a*) General 2–2
      - (*b*) Duration 2–3
      - (*c*) Impulse and wave forms 2–3
  - *c.* Surface influences 2–3
    - (1) General 2–3
      - (*a*) Good surface conditions 2–5
      - (*b*) Average surface conditions 2–5
    - (2) Time of arrival 2–5
    - (3) Peak overpressure 2–5
      - (*a*) General 2–5
      - (*b*) Duration 2–6
      - (*c*) Impulse and wave forms 2–6
    - (4) Dynamic pressure 2–6
      - (*a*) General 2–6
      - (*b*) Duration 2–7
      - (*c*) Impulse and wave forms 2–7
  - *d.* Other influences on air blast propagation 2–7
    - (1) General 2–7
    - (2) Atmospheric effects 2–8
      - (*a*) Effects of rain and fog 2–8
      - (*b*) Effects of temperature inversions 2–8
      - (*c*) Effects of altitude 2–8
    - (3) Effects of topography 2–9
      - (*a*) General 2–9
      - (*b*) Terrain 2–9
      - (*c*) Cities 2–10
      - (*d*) Forests 2–10
    - (4) Surface conditions 2–10
      - (*a*) General 2–10
      - (*b*) Thermal influences 2–11
      - (*c*) Precursor characteristics 2–11
      - (*d*) Mechanical influences 2–11
  - *e.* Air blast from a subsurface explosion 2–13
    - (1) General 2–13
    - (2) Underground 2–13
    - (3) Underwater 2–13
- 2.2 Ground Shock and Cratering Phenomena 2–49
  - *a.* Cratering 2–49
    - (1) Land 2–49
      - (*a*) General 2–49
      - (*b*) True and apparent craters 2–49
      - (*c*) Crater radius and depth 2–49
      - (*d*) Crater lip 2–49
      - (*e*) Rupture zone 2–49
      - (*f*) Plastic zone 2–51
      - (*g*) Height and depth of burst 2–51
      - (*h*) Effect of slope 2–51

PART ONE. PHYSICAL PHENOMENA—Continued

SECTION II. BLAST AND SHOCK PHENOMENA—Continued

2.2 Ground Shock and Cratering Phenomena—Continued

a. Cratering—Continued

Page
(2) Underwater 2–51
(a) General 2–51
(b) Burst geometry 2–51
b. Ground shock 2–52
(1) General 2–52
(2) Direct ground shock 2–52
(a) Propagation 2–52
(b) Pressure (stress) 2–54
(c) Acceleration of soil particles 2–54
(d) Displacement of soil particles 2–54
(3) Air induced ground shock 2–55
(a) Propagation 2–55
(b) Pressure (stress) 2–55
(c) Acceleration of soil particles 2–55
(d) Displacement of soil particles 2–55
c. Column and base surge 2–55
2.3 Water Shock and Surface Phenomena 2–56
a. Water shock 2–56
(1) General 2–56
(2) Burst geometry 2–56
(a) Deep burst in deep water 2–56
(b) Shallow burst in deep water 2–57
(c) Shallow water burst 2–58
(3) Cavitation collapse 2–58
(4) Refraction 2–58
b. Waves 2–58
(1) General 2–58
(2) Burst geometry 2–60
(a) Shallow water burst 2–60
(b) Deep water burst 2–60
(3) Terminal waves 2–60
c. Column and base surge 2–60
(1) Shallow burst 2–60
(2) Deep burst 2–61
(3) Intermediate depths 2–61
(4) Growth 2–61

SECTION III. THERMAL RADIATION PHENOMENA

3.1 General 3–1
3.2 Thermal Scaling 3–1
a. General 3–1
b. Thermal pulse 3–1
c. Time scaling 3–2
d. Thermal yield 3–2
3.3 Radiant Explosure vs. Slant Range 3–2
a. Spectral characteristics 3–2
b. Atmospheric transmissivity 3–2
c. Reflection 3–3
d. Calculation of radiant exposure 3–3
3.4 Other Influences on Thermal Radiation Propagation 3–4
a. Topography and clouds 3–4
b. Fog and smoke 3–4
c. The Wilson Cloud 3–4

PART ONE. PHYSICAL PHENOMENA—Continued

SECTION IV. NUCLEAR RADIATION PHENOMENA

Page
4.1 General 4-1
  a. Radiations produced 4-1
  b. Relative importance 4-1
  c. Units 4-1
4.2 Initial Radiation 4-1
  a. Gamma radiation 4-1
    (1) General 4-1
    (2) Surface burst 4-2
    (3) Burst in the transition zone 4-3
    (4) Air burst 4-3
    (5) Exceptional cases 4-3
    (6) Subsurface bursts 4-3
  b. Neutron radiation 4-3
  c. Delivery rate 4-4
4.3 Residual Radiation 4-27
  a. General 4-27
  b. Air burst 4-27
  c. Surface burst 4-28
    (1) Land surface burst 4-28
      (a) General 4-28
      (b) Deposition patterns 4-28
      (c) Idealized contours 4-29
      (d) Decay rate 4-30
      (e) Dose rate contour dimensions 4-30
    (2) Water surface burst 4-30
      (a) General 4-30
      (b) Shallow water 4-31
  d. Burst in the transition zone 4-31
  e. Subsurface burst 4-32
    (1) Underground burst 4-32
    (2) Underwater burst 4-32
      (a) General 4-32
      (b) Harbor burst 4-32
  f. Ground zero dose rates 4-33
  g. Total dose received 4-33
  h. Dose contours 4-33
  i. Neutron-induced activity 4-65
    (1) Air burst 4-65
    (2) Burst in the transition zone 4-65
    (3) Surface and subsurface bursts 4-66
  j. Residual beta radiation 4-66
  k. Shielding 4-66
  l. Cloud contamination 4-67

PART TWO. DAMAGE CRITERIA

SECTION V. INTRODUCTION

5.1 General 5-1
5.2 Blast and Shock Damage 5-1
  a. General 5-1
  b. Loading 5-1
    (1) Air blast loading 5-1
      (a) Diffraction loading 5-2
      (b) Drag loading 5-3
      (c) Net loading 5-3
      (d) Target motion 5-4
      (e) Regular and Mach reflection 5-4
      (f) Non-ideal wave forms 5-4
    (2) Water shock loading 5-4
    (3) Ground shock loading 5-6

PART TWO. DAMAGE CRITERIA—Continued

SECTION V. INTRODUCTION—Continued

5.2 Blast and Shock Damage—Continued Page
- *c.* Response and damage 5–6

5.3 Thermal Radiation Damage 5–7
- *a.* General 5–7
- *b.* Energy and rate dependence 5–7
- *c.* Damage mechanisms 5–8
- *d.* Effect of thickness 5–8
- *e.* Effect of orientation 5–8
- *f.* Effect of shielding 5–8
- *g.* Moisture content 5–8

5.4 Nuclear Radiation 5–9
- *a.* Relative effects 5–9
- *b.* Cumulative effects 5–9
- *c.* Shielding 5–9

5.5 Selection of Burst 5–9
- *a.* General considerations 5–9
  - (1) Surface bursts 5–9
  - (2) Air bursts 5–9
  - (3) Subsurface bursts 5–10
- *b.* Estimation of phenomena extent 5–10

SECTION VI. PERSONNEL CASUALTIES

6.1 Air Blast and Mechanical Injury 6–1
- *a.* General 6–1
- *b.* Direct blast injury 6–1
  - (1) Crushing forces 6–1
  - (2) Translational forces 6–1
    - (*a*) Mechanisms 6–1
    - (*b*) Criteria for injury 6–2
- *c.* Indirect blast injury 6–2
  - (1) General 6–2
  - (2) Personnel in structures 6–2
  - (3) Personnel in vehicles 6–3
  - (4) Personnel in the open 6–3

6.2 Thermal Injury 6–3
- *a.* Introduction 6–3
- *b.* Primary radiant energy burns 6–4
- *c.* Burns under clothing 6
- *d.* The combat ineffective 6–
- *e.* Thermal shielding 6–
  - (1) General 6–5
  - (2) Evasive action 6–5
- *f.* Specific effects on the eye 6–5
- *g.* Secondary flame burns and conflagration effects 6–6

6.3 Nuclear Radiation Injury 6–6
- *a.* General 6–6
- *b.* External radiation hazard 6–6
  - (1) Gamma radiation 6–6
  - (2) Neutrons 6–7
  - (3) Beta particles 6–8
    - (*a*) General 6–8
    - (*b*) Effect 6–8
    - (*c*) Decontamination 6–8
- *c.* Internal radiation hazard 6–8
  - (1) General 6–8
  - (2) Importance 6–9
  - (3) Protective measures 6–9
- *d.* Immediate incapacitation 6–9

PART TWO. DAMAGE CRITERIA—Continued

SECTION VI. PERSONNEL CASUALTIES—Continued

Page
6.4 Combined Injury
6.5 Nuclear Radiation Shielding 6–9
  a. General 6–9
  b. Initial radiation 6–10
  c. Residual radiation 6–10

SECTION VII. DAMAGE TO STRUCTURES

7.1 General 7–1
  a. Comparison of effects 7–1
  b. Air blast damage 7–1
  c. Ground shock damage 7–1
  d. Water shock damage 7–1
7.2 Surface Structures 7–1
  a. Air blast 7–1
    (1) General 7–1
    (2) Loading during the diffraction phase 7–2
    (3) Loading during the drag phase 7–2
    (4) Damage to structures 7–2
      (a) Structural characteristics 7–2
      (b) Shallow underground bursts 7–5
      (c) Damage classification 7–5
  b. Ground shock and cratering 7–6
  c. Thermal radiation damage 7–6
7.3 Underground Structures 7–7
  a. Air blast 7–7
  b. Ground shock and cratering 7–7
    (1) Relatively small, highly resistant targets in soil 7–7
    (2) Moderate size, moderately resistant targets 7–7
    (3) Long, relatively flexible targets 7–7
    (4) Orientation sensitive targets 7–7
    (5) Rock tunnels 7–7
    (6) Large underground installations 7–7
  c. Damage criteria 7–7
    (1) Air blast damage 7–7
    (2) Ground shock and cratering damage 7–7
      (a) Structures in soil 7–7
      (b) Tunnels in rock 7–8
      (c) Utility connections 7–8
      (d) Displacement-sensitive targets 7–8
    (3) Crater and missile damage 7–8
7.4 Field Fortifications 7–8
  a. Air blast 7–8
    (1) Revetments 7–9
    (2) Overhead cover 7–9
  b. Ground shock and cratering 7–9
  c. Thermal radiation damage 7–9
7.5 Dams and Harbor Installations 7–9
  a. Air blast 7–9
    (1) Concrete gravity dams 7–9
    (2) Harbor installations 7–10
  b. Water shock 7–10
  c. Cratering 7–10
  d. Water waves 7–10
    (1) Impact and hydrostatic pressure 7–11
    (2) Drag force 7–11
    (3) Inundation 7–11
  e. Thermal radiation damage 7–11

PART TWO. DAMAGE CRITERIA—Continued

SECTION VIII. DAMAGE TO NAVAL EQUIPMENT

Page
8.1 General 8–1
  a. Damage mechanisms 8–1
  b. Damage classification for surface ships 8–1
    (1) Severe damage (probable sinking) 8–1
    (2) Moderate damage (immobilization) 8–1
    (3) Light damage 8–1
  c. Damage classification for submarines 8–1
    (1) Lethal hull damage 8–1
    (2) Interior shock damage (surfacing damage) 8–1
8.2 Surface Ship Damage 8–1
  a. Water shock damage 8–1
  b. Air blast damage 8–2
  c. Water wave damage 8–2
  d. Thermal damage 8–2
8.3 Subsurface Target Damage 8–2
  a. Submarines 8–2
    (1) Air blast damage 8–2
    (2) Water shock damage 8–2
  b. Underwater mines 8–3

SECTION IX. DAMAGE TO AIRCRAFT

9.1 General 9–1
9.2 Parked Aircraft 9–1
  a. Air blast 9–1
  b. Thermal radiation 9–2
9.3 Aircraft in Flight 9–2
  a. Air blast 9–2
  b. Thermal radiation 9–2

SECTION X. DAMAGE TO MILITARY FIELD EQUIPMENT

10.1 General 10–1
  a. Damage mechanisms 10–1
  b. Damage levels 10–1
  c. Terrain effects 10–1
  d. Subsurface bursts 10–2
  e. Scaling 10–2
10.2 Ordnance Equipment 10–2
  a. Blast damage 10–2
  b. Thermal damage 10–2
10.3 Supply Dumps 10–2
  a. Blast damage 10–2
    (1) Severe 10–2
    (2) Light 10–2
  b. Thermal damage 10–2
10.4 Communications Equipment 10–3
  a. Blast damage 10–3
  b. Thermal damage 10–3
10.5 Land Mines 10–3
  a. General 10–3
  b. Effects of burial depth and soil type 10–3
  c. Sympathetic actuation 10–3
  d. Effects of blast wave characteristics 10–5
  e. Mine type 10–5
  f. Criteria 10–5
10.6 Railroad Equipment 10–5
  a. Blast damage 10–5
    (1) General 10–5
    (2) Isolated box cars, flat cars, gondolas and full tank cars 10–5
    (3) Isolated empty tank cars 10–6

PART TWO. DAMAGE CRITERIA—Continued

SECTION X. DAMAGE TO MILITARY FIELD EQUIPMENT—Continued

10.6 Railroad Equipment—Continued
  a. Blast damage—Continued
Page
    (4) Isolated locomotives 10–6
    (5) Roadbeds 10–6
    (6) Marshalling yard structures 10–6
  b. Shielding 10–6
  c. Thermal damage 10–6
10.7 Engineer Heavy Equipment 10–6
  a. Blast damage 10–6
  b. Thermal damage 10–6
10.8 Miscellaneous Equipment 10–6
  a. General 10–6
  b. Wire entanglements 10–7
  c. Tentage 10–7
10.9 Drag Shielding for Military Equipment 10–7
  a. Gross terrain shielding 10–7
  b. Effects of "digging-in" 10–7

SECTION XI. FOREST STANDS

11.1 General 11–1
11.2 Air Blast 11–1
  a. General 11–1
    (1) Type I stand 11–1
    (2) Type II stand 11–1
    (3) Type III stand 11–1
  b. Air blast damage 11–2
11.3 Thermal Radiation 11–2
  a. General 11–2
  b. Ignitions 11–2
  c. Fire seasons 11–2
  d. Kindling fuels 11–3
  e. Burning potential 11–3
  f. Fire spread 11–3

SECTION XII. MISCELLANEOUS RADIATION DAMAGE CRITERIA

12.1 Fire in Urban Areas 12–1
  a. General 12–1
  b. Ignition points 12–1
  c. Humidity effects 12–1
  d. Fire spread 12–1
12.2 Nuclear Radiation Damage 12–2
  a. Neutron irradiation 12–2
    (1) Free air neutron flux 12–2
    (2) Permanent damage 12–2
    (3) Induced activity 12–2
  b. Gamma radiation 12–2
  c. Electromagnetic radiation 12–2
12.3 Thermal Damage to Various Materials 12–2

APPENDIX I. SUPPLEMENTARY BLAST DATA

I.1 Shock Wave Propagation in Free Air I–1
  a. Rankine-Hugoniot relationships I–1
  b. Overpressure positive phase impulse and wave form in free air I–1
  c. Dynamic pressure impulse and wave form I–2
I.2 Blast Wave Perturbations I–2
  a. Overpressure positive phase impulse and wave forms I–2
  b. Dynamic pressure wave forms I–4
I.3 Altitude Conversion of Air Blast Properties I–4
  a. General I–4
  b. Conversion procedure I–6

PART TWO. DAMAGE CRITERIA—Continued

APPENDIX I. SUPPLEMENTARY BLAST DATA—Continued Page

I.4 Blast Wave Reflection I-7
I.5 Surface Burst I-7

II. USEFUL RELATIONSHIPS

II.1 General II-1
II.2 Thermal II-1
II.3 Nuclear II-2
III. GLOSSARY III-1
IV. BIBLIOGRAPHY IV-1
INDEX 1

FIGURES:

1-1 Development of an Air Burst 1-3
1-2 Development of a Surface Burst 1-6
1-3 Development of a Shallow Underground Burst 1-9
1-4 Development of a Deep Underground Burst 1-10
1-5 Development of a Shallow Underwater Burst 1-11
1-6 Development of a Deep Underwater Burst 1-13
2-1 Ideal Pressure-Time Relations for a Blast Wave in the Low Pressure Region 2-1
2-2 Free Air Time of Arrival of Shock Front 2-15
2-3 Free Air Overpressure 2-17
2-4 Free Air Duration of Positive Phase 2-19
2-5 Free Air Peak Dynamic Pressure 2-21
2-6 Growth of the Mach Stem 2-4
2-7 Mach Stem Height 2-23
2-8 Blast Wave Arrival Times at the Surface 2-26
2-9 Peak Overpressures on the Surface-Good Surface Conditions 2-30
2-10 Peak Overpressures on the Surface-Average Surface Conditions 2-32
2-11 Positive Phase Duration on the Surface 2-36
2-12 Peak Dynamic Pressure on the Surface-Good Surface Conditions 2-40
2-13 Peak Dynamic Pressure on the Surface-Average Surface Conditions 2-41
2-14 Rain or Fog Effects on Peak Overpressure 2-43
2-15 Relative Blast Yield vs. Altitude of Burst 2-9
2-16 Precursor Characteristics 2-12
2-17 Criteria for Precursor Formation 2-45
2-18 Peak Air Overpressures at the Surface as a Function of Depth of Burst in Earth or Water and Horizontal Range 2-47
2-19 Crater Profile 2-50
2-20 Crater Radius vs. Burst Position in Dry Soil or Soft Rock 2-63
2-21 Crater Depth vs. Burst Position in Dry Soil or Soft Rock 2-65
2-22 Apparent Crater Diameter vs. Yield in Dry Soil or Soft Rock 2-68
2-23 Apparent Crater Depth vs. Yield in Dry Soil or Soft Rock 2-72
2-24 Crater Diameter vs. Yield for Underwater Cratering 2-76
2-25 Crater Depth vs. Yield for Underwater Cratering 2-78
2-26 Crater Lip Heights vs. Yield for Underwater Cratering 2-80
2-27 Direct and Air Induced Ground Shock and Ground Acceleration Wave Form 2-53
2-28 Peak Air Blast Induced Ground Acceleration 2-83
2-29 Base Surge for Underground Bursts 2-86
2-30 Effect of Cut-Off on the Shape of the Positive Phase 2-56
2-31 Peak Water Overpressure in Deep Underwater Bursts 2-89
2-32 Surface Reflection Effects 2-57
2-33 Wave Front Propagation in Water 2-59
2-34 Maximum Wave Height for Water Bursts 2-91
2-35 Base Surge for Underwater Bursts 2-94
3-1 Fireball Radius and Apparent Temperature vs. Time for a 20 KT Air Burst 3-5
3-2 Scaled Radiant Power and Percent Thermal Radiation Emitted vs. Time 3-7
3-3 Time to Second Radiant Power Maximum and Time to Minimum vs. Yield 3-10
3-4 Relative Thermal Yield vs. Burst Altitude 3-12
3-5 Atmospheric Transmissivity 3-14

FIGURES—Continued

Page
3–6 Radiation Exposure from Air and Surface Bursts 3–18
4–1 Initial Gamma Radiation Dose, Relative Air Density 1.1 4–10
4–2 Initial Gamma Radiation Dose, Relative Air Density 1.0 4–11
4–3 Initial Gamma Radiation Dose, Relative Air Density 0.9 4–12
4–4 Initial Gamma Radiation Dose, Relative Air Density 0.8 4–13
4–5 Initial Gamma Radiation Dose, Relative Air Density 0.6 4–14
4–6 Initial Gamma Radiation Dose, Relative Air Density 0.4 4–15
4–7 Initial Gamma Radiation Dose, Relative Air Density 0.2 4–16
4–7a Initial Gamma Radiation Dose (Sub-Kiloton), Relative Air Density 1.1 4–16a
4–7b Initial Gamma Radiation Dose (Sub-Kiloton), Relative Air Density 1.0 4–16b
4–7c Initial Gamma Radiation Dose (Sub-Kiloton), Relative Air Density 0.9 4–16c
4–7d Initial Gamma Radiation Dose (Sub-Kiloton), Relative Air Density 0.8 4–16d
4–8 Initial Gamma Radiation Dose for an Underground Burst 4–19
4–9 Percentage of Total Dose of Initial Gamma Radiation vs. Time After Detonation 4–20
4–10 Neutron Radiation Dose (Fission Weapons) 4–22a
4–10a Prompt Neutron Radiation Dose (Sub-Kiloton), Relative Air Density 1.1 4–22b
4–10b Prompt Neutron Radiation Dose (Sub-Kiloton), Relative Air Density 1.0 4–22c
4–10c Prompt Neutron Radiation Dose (Sub-Kiloton), Relative Air Density 0.9 4–22d
4–10d Prompt Neutron Radiation Dose (Sub-Kiloton), Relative Air Density 0.8 4–23
4–11 Neutron Radiation Dose (Fusion Weapons) 4–25
4–12 Generalized Local Contours for Residual Radiation 4–29
4–13 Fission Product Decay Factors From One Hour After Detonation 4–35
4–14 Land Surface Burst Dose Rate Contour Areas 4–38
4–15 Land Surface Burst Dose Rate Contour Downwind Distances 4–40
4–16 Land Surface Burst Dose Rate Contour Crosswind Distances 4–42
4–17 Land Surface Burst Dose Rate Contour Ground Zero Circle Diameters 4–44
4–18 Downwind Displacement of Ground Zero Circle 4–46
4–19 Height of Burst Adjustment Factor for Dose Rate Contour Values 4–48
4–20 Underground Burst Dose Rate Contour Areas 4–53
4–21 Underground Burst Dose Rate Contour Downwind Distances 4–54
4–22 Underground Burst Dose Rate Contour Crosswind Distances 4–55
4–23 Underground Burst Dose Rate Contour Ground Zero Circle Diameters 4–56
4–24 Depth Multiplication Factor for Linear Contour Dimensions 4–57
4–25 Harbor Burst Dose Rate Contour Areas 4–59
4–26 Total Radiation Dose Received in Contaminated Area 4–61
4–27 48-Hour Dose Scaling Factor 4–63
4–28 Neutron-Induced Gamma Activity 4–70
4–29 Decay Factors for Neutron-Induced Gamma Activity 4–73
4–30 Total Neutron-Induced Gamma Dose—Soil Type I 4–75
4–31 Total Neutron-Induced Gamma Dose—Soil Type II (Nevada) 4–76
4–32 Total Neutron-Induced Gamma Dose—Soil Type III 4–77
4–33 Total Neutron-Induced Gamma Dose—Soil Type IV 4–78
4–34 Stabilized Cloud Altitudes 4–81
4–35 Cloud Height Growth 4–83
4–36 Cloud Diameter Growth 4–84
4–37 Dose Received While Flying Through a Nuclear Cloud 4–87
5–1 Net Blast Loading on Representative Structures 5–5
5–2 Phenomena at Various Scaled Burst Heights 5–13
5–3 Phenomena Nomograms for Various Scaled Burst Heights 5–18
6–1 Direct Blast Casualties to Personnel in the Open 6–13
6–2 Critical Radiant Exposures—1st and 2d Degree Burns on Bare Skin 6–14
6–3 Percent Thermal Radiation Emitted vs. Time 6–15
6–4 Immediate Casualty Production by Various Physical Phenomena 6–17
6–5 Shielding from Initial Gamma Radiation 6–19
6–6 Shielding from Residual Gamma Radiation 6–20
7–1 Multistory Blast Resistant Designed Reinforced Concrete Building—Severe Damage 7–14
7–2 Multistory Reinforced Concrete Building With Concrete Walls and Small Window Area—Severe Damage 7–16
7–3 Multistory Wall-Bearing Building, Apartment House Type—Severe Damage 7–18

Page

FIGURES—Continued

7-4 Monumental Type Multistory Wall-Bearing Building—Severe Damage 7-20
7-5 Wood Frame Buildings—Severe Damage 7-22
7-6 Filled Oil Storage Tank—Severe Damage 7-24
7-7 Light Steel Frame Industrial Building—Severe Damage 7-26
7-8 Heavy Steel Frame Industrial Building—Severe Damage 7-28
7-9 Multistory Steel Frame Office Building—Severe Damage 7-30
7-10 Reinforced Concrete Frame Office Building—Severe Damage 7-32
7-11 Highway and Railway Truss Bridges (150′ to 250′ span)—Severe Damage 7-34
7-12 Highway and Railway Truss Bridges (250′ to 500′ span)—Severe Damage 7-36
7-13 M-2 or M-4 Floating Bridges—Severe Damage 7-38
7-14 Earth Covered Light Steel Arch Shelter—Severe Damage 7-40
7-15 Earth Covered Light Reinforced Concrete Structures—Severe Damage 7-42
7-16 Horizontal Distance vs. Yield for Severe Damage—Structures Primarily Sensitive to Overpressure Loading, Surface Burst 7-45
7-17 Horizontal Distance vs. Yield for Severe Damage—Structures Primarily Sensitive to Drag Loading, Surface Burst 7-46
7-18 Subsurface Burst Damage Distance Reduction for Surface Structures 7-49
7-19 Damage to Unlined Tunnels in Sound Rock 7-51
7-20 Damage to Command Posts and Personnel Shelters 7-53
7-21 Damage to Machine Gun Emplacements 7-54
7-22 Damage to Unrevetted Foxholes and Trenches 7-55
8-1 Surface Ships—Severe Damage 8-6
8-2 Surface Ships—Moderate and Light Damage 8-7
8-3 Surface Ships—Light Damage 8-8
8-4 Submarine Lethal Hull Damage 8-10
8-5 Submarine Interior Shock Damage 8-11
8-6 Underwater Minefield Neutralization—50′ Water Depth 8-13
8-7 Underwater Minefield Neutralization—100′ Water Depth 8-14
8-8 Underwater Minefield Neutralization—200′ Water Depth 8-15
9-1 Damage to Parked Noncombat Aircraft 9-5
9-2 Damage to Parked Combat Aircraft, Random Orientation 9-7
9-3 Damage to Parked Combat Aircraft, Nose-On Orientation 9-9
9-4 Estimates of Gusts and Thermal Envelopes for Typical Combat Aircraft 9-11
10-1 Damage to Military Vehicles 10-9
10-2 Damage to Tanks and Artillery 10-11
10-3 Damage to Supply Dumps 10-13
10-4 Damage to Signal and Electronic Fire Control Equipment 10-15
10-5 Damage to Box Cars, Flat Cars, Full Tank Cars, and Gondolas 10-17
10-6 Damage to Railroad Locomotives 10-19
10-7 Damage to Exposed Engineer Heavy Equipment 10-21
10-8 Damage to Protected Engineer Heavy Equipment 10-23
11-1 Forest Stands, Type I—Severe Damage 11-7
11-2 Forest Stands, Type II—Severe Damage 11-8
11-3 Forest Stands, Type III—Severe Damage 11-9
11-4 Forest Stands, Type I—Light Damage 10-10
11-5 Forest Stands, Type II—Light Damage 11-11
11-6 Forest Stands, Type III—Light Damage 11-12
11-7 Wildland Kindling Fuel Ignition Requirements 11-15
12-1 Newspaper Ignition Requirements 12-5
12-2 Burning Potential for Urban Areas, Central Heating Not in Use 12-6
12-3 Burning Potential for Urban Areas, Central Heating in Use 12-7
12-4 Neutron Flux for a Typical Fission Weapon 12-9
12-5 Fireball Effects on Various Materials 12-10
I-1 Free Air Shock Velocity I-9
I-2 Free Air Peak Particle Velocity I-10
I-3 Shock Front Parameters as a Function of Peak Overpressure I-11
I-4 Free Air Overpressure Positive Phase Impulse I-13
I-5 Free Air Overpressure Decay I-15
I-6 Comparison of Simplified Wave Forms for Overpressure and Dynamic Pressure I-16

Page

FIGURES—Continued

I–7 Free Air Dynamic Pressure Impulse I–19
I–8 Free Air Dynamic Pressure Decay I–21
I–9 Overpressure Positive Phase Impulse at the Surface I–24
I–10 Wave Form Classification for Peak Overpressure I–3
I–11 Overpressure Wave Form Variations at the Surface I–29
I–12 Wave Form Classification for Dynamic Pressure I–5
I–13 Altitude Conversion Factors I–29
I–14 Sea Level Blast Parameters for Altitude Conversion for Airborne Targets I–30
I–15 Reflection Chart for Peak Overpressures Under Ideal Conditions I–31
I–16 Peak Overpressure for a Surface Burst I–32
II–1 Fractional Powers II–6
II–2 Slant Range Nomogram II–8
II–3 Relative Air Density (Standard Atmosphere) II–9
II–4 Atmospheric Water Vapor Density II–10

TABLES:

2–1 Related Values Among Various Air Blast Parameters 2–3
4–1 Typical Relative Air Densities (R) at Various Altitudes 4–2
4–2 Chemical Composition of Illustrative Soils 4–66
6–1 Estimated Casualty Production in Structures for Various Degrees of Structural Damage 6–3
6–2 Critical Radiant Exposure for Burns Under Clothing 6–4
6–3 Combat Ineffectives Due to Thermal Energy 6–5
6–4 Probable Effects of Acute Whole Body Gamma Radiation Doses 6–7
6–5 Dose Transmission Factors (Interior Dose/Exterior Dose) 6–11
7–1 Damage to Types of Structures Primarily Affected by Blast Wave Overpressure During the Diffraction Phase 7–3
7–2 Damage to Types of Structures Primarily Affected by Dynamic Pressure During the Drag Phase 7–4
7–3 Damage Criteria for Underground Structures 7–8
7–4 Damage Criteria for Field Fortifications 7–9
8–1 Surface Ship Peak Air Overpressure Damage Criteria 8–2
10–1 Damage to Ordnance Items 10–2
10–2 Overpressure in psi Required To Detonate Various Mines 10–4
11–1 Percentage of Trees Broken for Light and Severe Damage to Forest Stands 11–2
11–2 Condition of Wildland Fuels During Fire Season 11–3
11–3 Classes of Thin Wildland Kindling Fuels 11–3
11–4 Burning Potential for Light Wildland Fuels During Fire Season 11–4
12–1 Relative Incidence of Ignitions in Metropolitan Areas of the United States by Land-Use Classes 12–1
12–2 Critical Radiant Exposure Values for Various Materials 12–3
II–1 Standard Atmospheric Conditions II–3
II–2 Average Atmosphere II–4

transformation of 2.65 grams of matter into energy, with an energy release equivalent to that resulting from the detonation of 57,000 tons of TNT.

b. Another method of rating in common usage, and one which is often confused with the rating of *energy* in terms of TNT *energy* equivalence, is the rating of *effects* in terms of TNT *effects* equivalence, i. e., the *effect* of a particular phenomenon of a nuclear detonation expressed in terms of the amount of TNT which would produce the same *effect*. An example of TNT effect equivalence would be the expression of the crater radius of a nuclear surface burst in terms of the amount of TNT which would be required to produce the same radius.

c. For convenience these TNT equivalences are expressed in 1,000 ton or 1,000,000 ton units, KT (kiloton) or MT (megaton), where 1 ton equals 2,000 pounds and the energy content of TNT is defined as 1100 calories per gram.

d. A "nominal" weapon is one the yield of which is 20 KT. The use of this term arose from the approximately 20 KT yields at Hiroshima, Nagasaki, and the Bikini (Crossroads) tests. In some reports nuclear weapons effects data are based on the nominal weapon.

1.3 Data Presentation

This manual is divided into two parts. Part One, *Physical Phenomena*, treats the basic phenomena of blast and shock, thermal radiation, and nuclear radiation resulting from a nuclear explosion in various media and under various conditions. Part Two, *Damage Criteria*, discusses the mechanism of casualty production and damage to military targets, correlating the basic physical phenomena of a nuclear detonation with various defined degrees of damage.

Relatively simple scaling procedures exist for relating the majority of phenomena associated with weapons of one yield to weapons of other yields. For simplicity and convenience in the use of the manual, most physical phenomena data and much of the damage data are presented for 1 KT bursts, from which the phenomena or damage for other yields may be readily obtained by means of the appropriate scaling procedures which are explained wherever their use is required.

An estimate of the degree of reliability accompanies the presentation of nearly all physical phenomena data. This estimated reliability indicates a range of values above and below the curve such that, for a large number of events, 90 percent of the data will fall within this range. Statements regarding reliability of damage data, on the other hand, describe the source and relative quantity of the data. Reliability estimates do not include operational considerations such as aiming error, target intelligence, and height of burst or yield variations.

1.4 Types of Burst

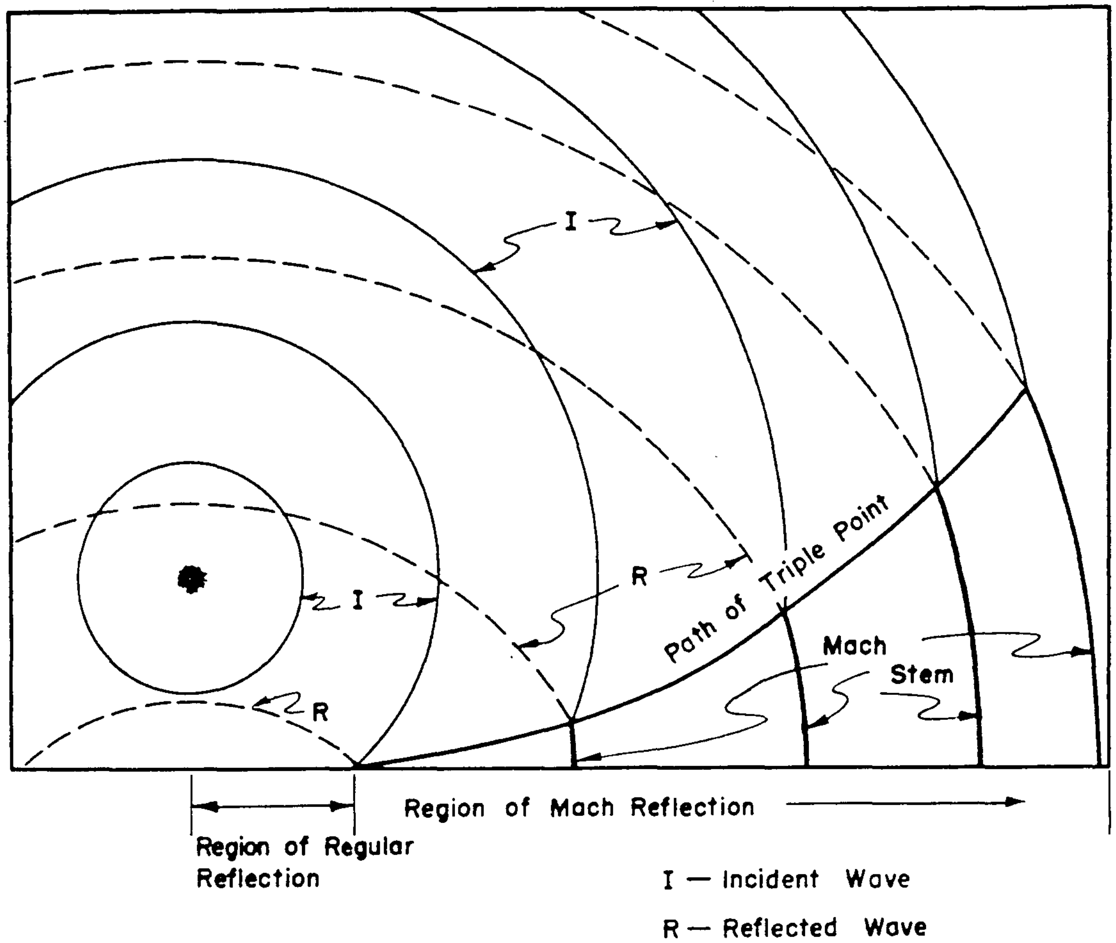
a. General. The medium in which a weapon is burst determines in great measure the relative magnitudes of the various physical phenomena. In particular, large differences result depending upon whether the detonation occurs in air above the surface, at the surface, or beneath the surface. It is often convenient to discuss weapon phenomena by these types of burst.

b. Brief Description of an Air Burst.

(1) *Definition.* An air burst is defined as the explosion of a nuclear weapon at such a height that the weapon phenomenon of interest is not significantly modified by the earth's surface. For example, from a blast standpoint, this height is such that the reflected wave passing through the fireball does not overtake the incident wave above the fireball (heights greater than about 160 $W^{1/3}$ feet ± 15%, where W is the weapon yield in kilotons). For thermal radiation an airburst occurs at such heights above the surface that the apparent thermal yield viewed from the ground is not affected by surface phenomena, such as heat transfer to the surface, distortion of the fireball by the reflected shock wave, thermal reflection from the surface, etc. (heights above the surface greater than about 180 $W^{0.4}$ feet ±20% for yields of 10 KT to 100 KT, and ±30% for other yields). From the standpoint of fallout, an airburst occurs at such heights that militarily significant local fallout does not result (for yields less than 100 KT, a minimum height of burst of 100 $W^{1/3}$ feet; for yields greater than 100 KT, in the absence of data,

FIGURE 2-6

GROWTH OF THE MACH STEM
(IDEALIZED)



The characteristics of the blast wave at or near the surface, as well as the formation of the Mach stem, are dependent upon yield, height of burst, and the boundary or reflecting surface conditions. The region where the incident and reflected shocks have not merged to form a Mach stem is often referred to as the region of regular reflection; the region where they have merged is referred to as the region of Mach reflection. As the Mach stem travels along the surface, the triple point (the point of intersection of the incident wave, reflected wave, and the Mach stem) rises. The estimated height of the Mach stem as a function of height of burst and distance from ground zero is given in figure 2–7, for a 1 KT burst. The procedure for scaling to other yields is illustrated in the example accompanying this figure. In addition to the fusing of the reflected and incident blast waves to form a Mach stem as just described, that portion of the reflected wave passing through the fireball of a burst in the transition zone will also fuse with that portion of the incident wave directly above the fireball. This fusion is primarily a result of the increased velocity of the reflected wave as it passes through the fireball, and as a consequence, is relatively narrow in lateral extent. As the height of burst varies from the surface to about 160 $W^{1/3}$, the peak overpressures in the fused wave above the fireball vary from those exupon the effective slope, positive or negative slopes may result in respective increases or decreases in peak overpressures by a factor of as much as two. The former is attributable to the reflection of the blast wave from the positive slope, whereas the latter is attributable to the diffraction of the blast wave as it moves over the crest of the hill and down the rear slope. In the Mach region, the qualitative changes in pulse or wave shape which occur for a positive slope are the formation of a spike on the front of the pulse at the base of the slope, and the gradual widening of this spike as the blast wave progresses up the slope. The peak pressure ratio (the ratio of the peak pressures on the slope to those which would exist in the absence of the slope) increases as the positive slope angle increases and the incident pressure decreases. On a negative slope, the qualitative changes in pulse shape which occur are a rounding of the front of the pulse at the beginning of the negative slope with a return to the normal shape as the blast wave moves down the slope. The peak pressure ratio in this instance is reduced as the negative slope angle increases and the incident pressure decreases. These changes in the pressure pulse apply to the gross terrain features only, and not to local accidents of the terrain. There is no known procedure for relating local terrain accidents to gross terrain features.

Contrary to popular opinion, a "line of sight" concept does not apply to blast shielding by terrain features. However, severe local irregularities or terrain accidents may result in significant shielding from drag or dynamic pressure effects. In addition, the effects of an isolated terrain feature on the blast wave are essentially limited to the immediate vicinity of the terrain feature itself. The total energy of the blast wave is such that recovery from perturbations is quite rapid. The precursor effects on the blast wave, when coupled with the effects of terrain features, are unknown, but are believed to be significant.

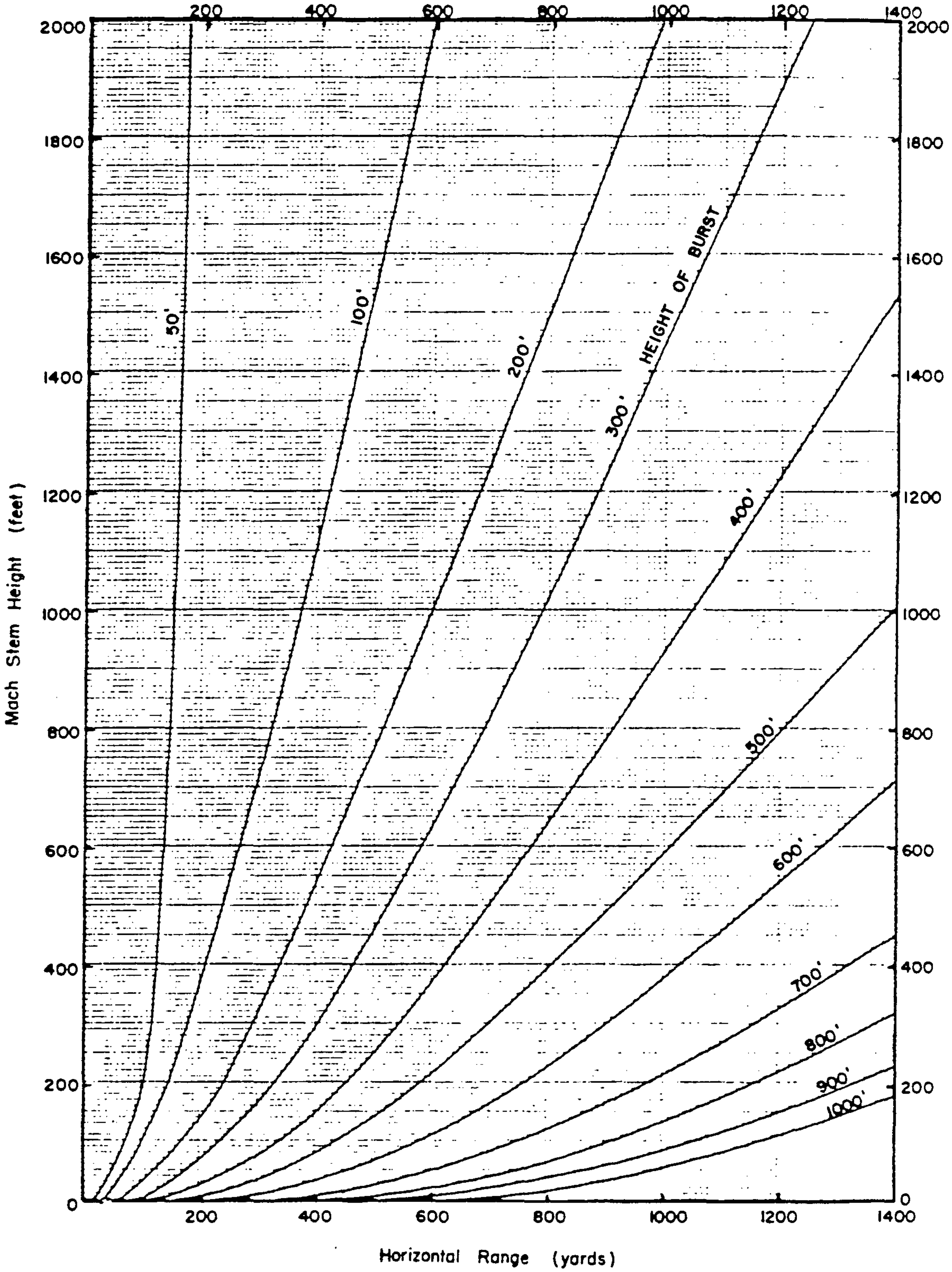
(*c*) *Cities.* As with terrain features, the effect of a city as a whole on blast wave phenomena is limited essentially to the immediate vicinity of the city itself. This gross effect is usually less significant than localized changes in the characteristics of a passing blast wave. Although some local shielding similar to that afforded by terrain accidents is expected to result from intervening objects and structures, reflection and channeling phenomena may, in certain instances, result in increases in peak overpressures and peak dynamic pressures. These local effects cannot be quantitatively related to the gross effects of cities on blast wave phenomena. The general air blast characteristics in cities and urban areas are essentially the same as those for open terrain of average surface conditions.

(*d*) *Forests.* Forests may be effective in altering blast wave characteristics. However, non-local effects are less significant than localized effects. The extent of the alteration depends on forest area, tree size, state of foliation, distance from ground zero, and other variables. The shielding provided within a forest is not well known. Air blast characteristics in forested areas are essentially the same as those for open terrain, average surface conditions.

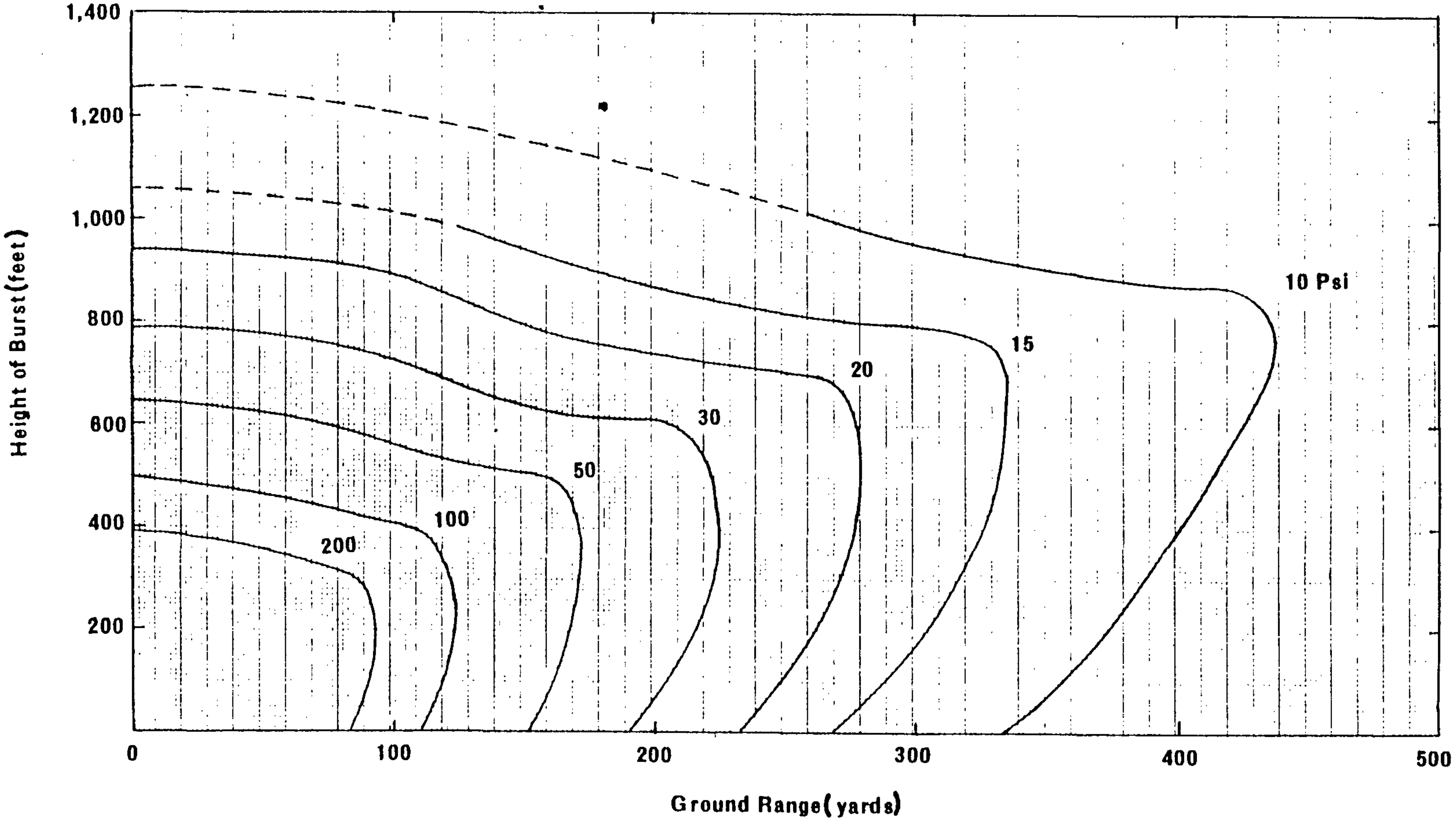
(4) *Surface conditions.*

(*a*) *General.* The nature of the surface over which the blast wave moves has been found to exert a considerable influence on the individual characteristics of the blast wave. For example, significant differences between the peak values of a given blast wave parameter may occur when considering the effects of a nuclear weapon burst over an

MACH STEM HEIGHT (1 KT)



PEAK OVERPRESSURE ON THE SURFACE AS A FUNCTION OF HEIGHT OF BURST AND HORIZONTAL RANGE
1 KT AT SEA LEVEL FOR GOOD SURFACE CONDITIONS



PEAK OVERPRESSURE ON THE SURFACE AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE
1 KT AT SEA LEVEL FOR GOOD SURFACE CONDITIONS

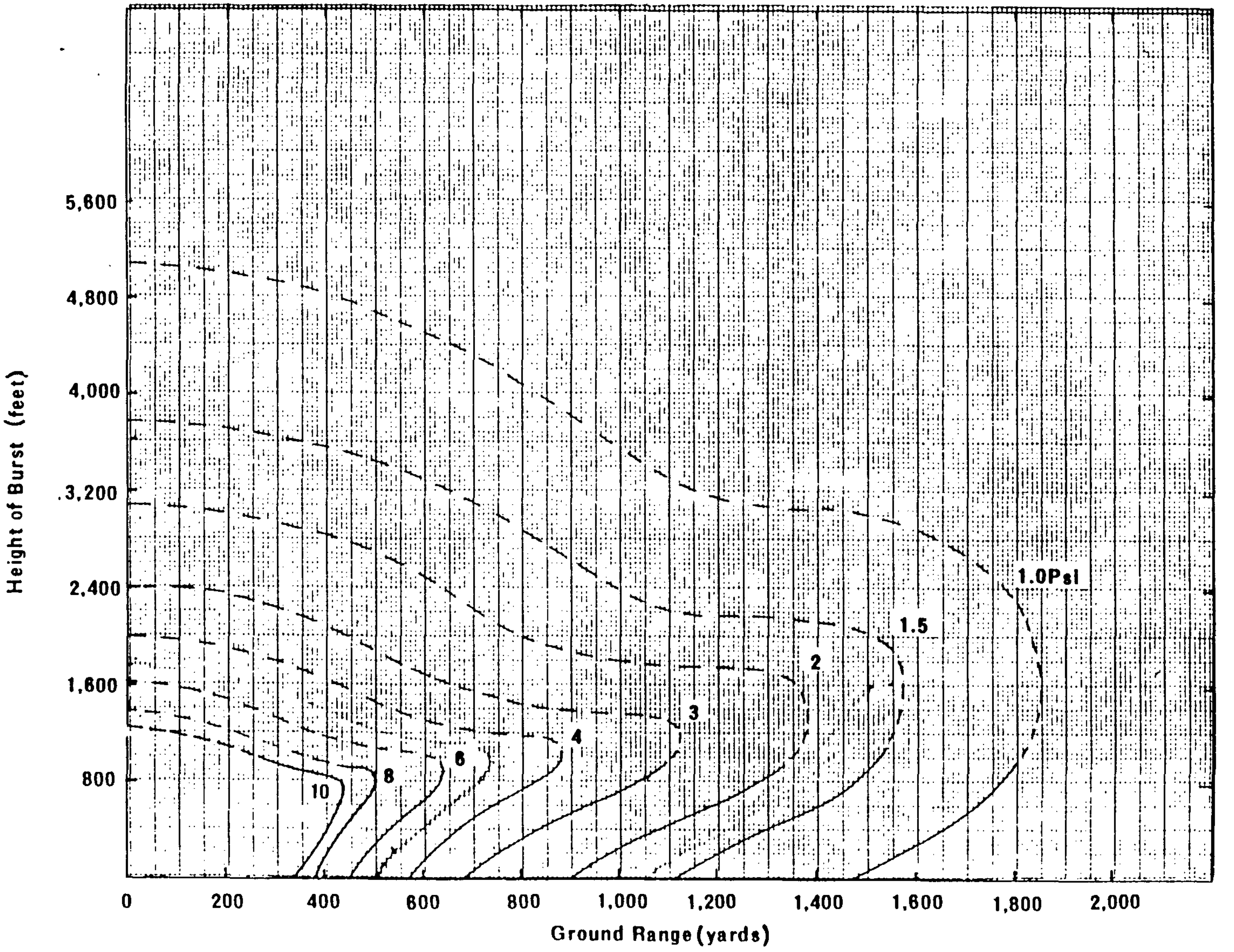
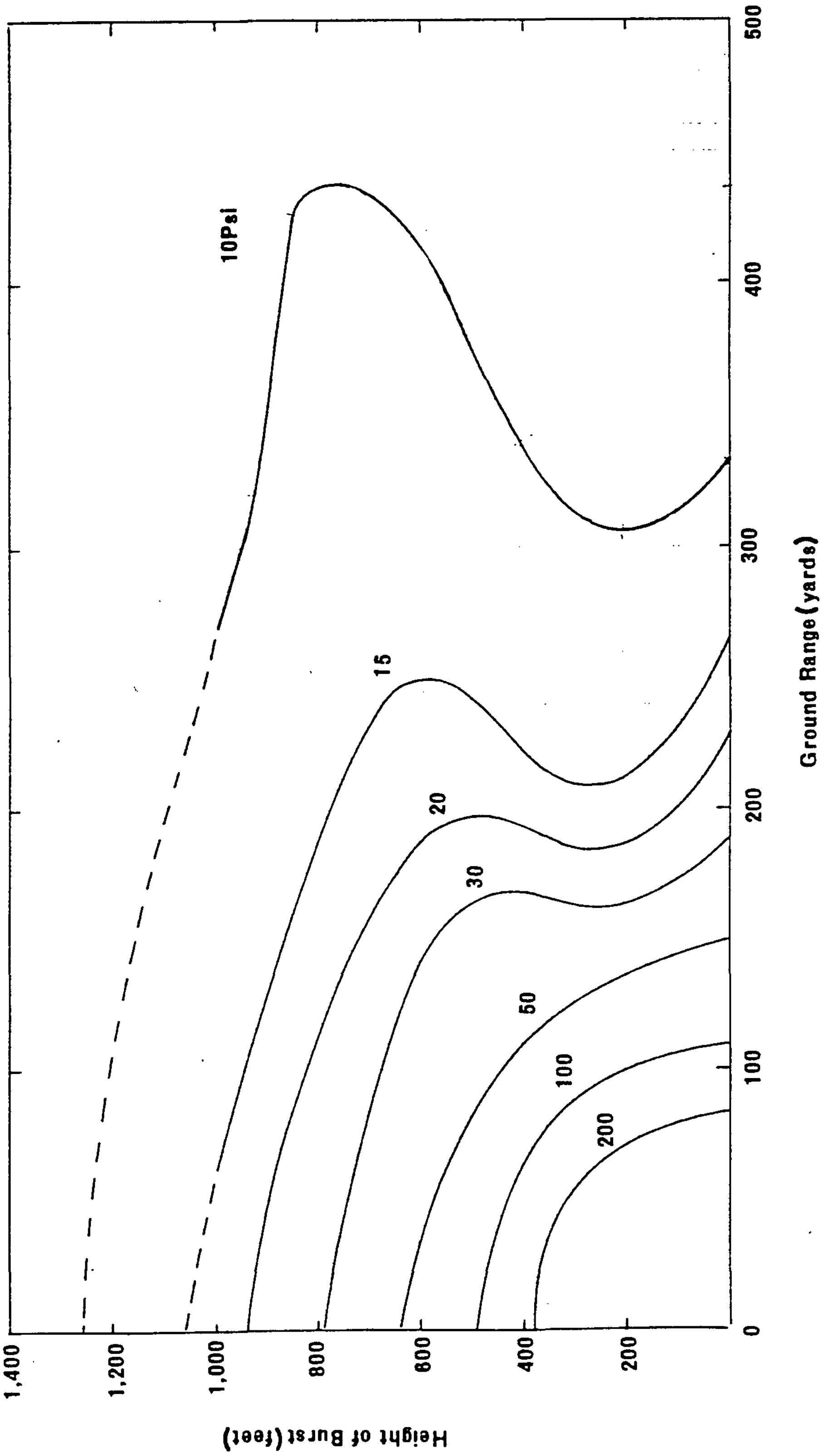


FIGURE 2-10A

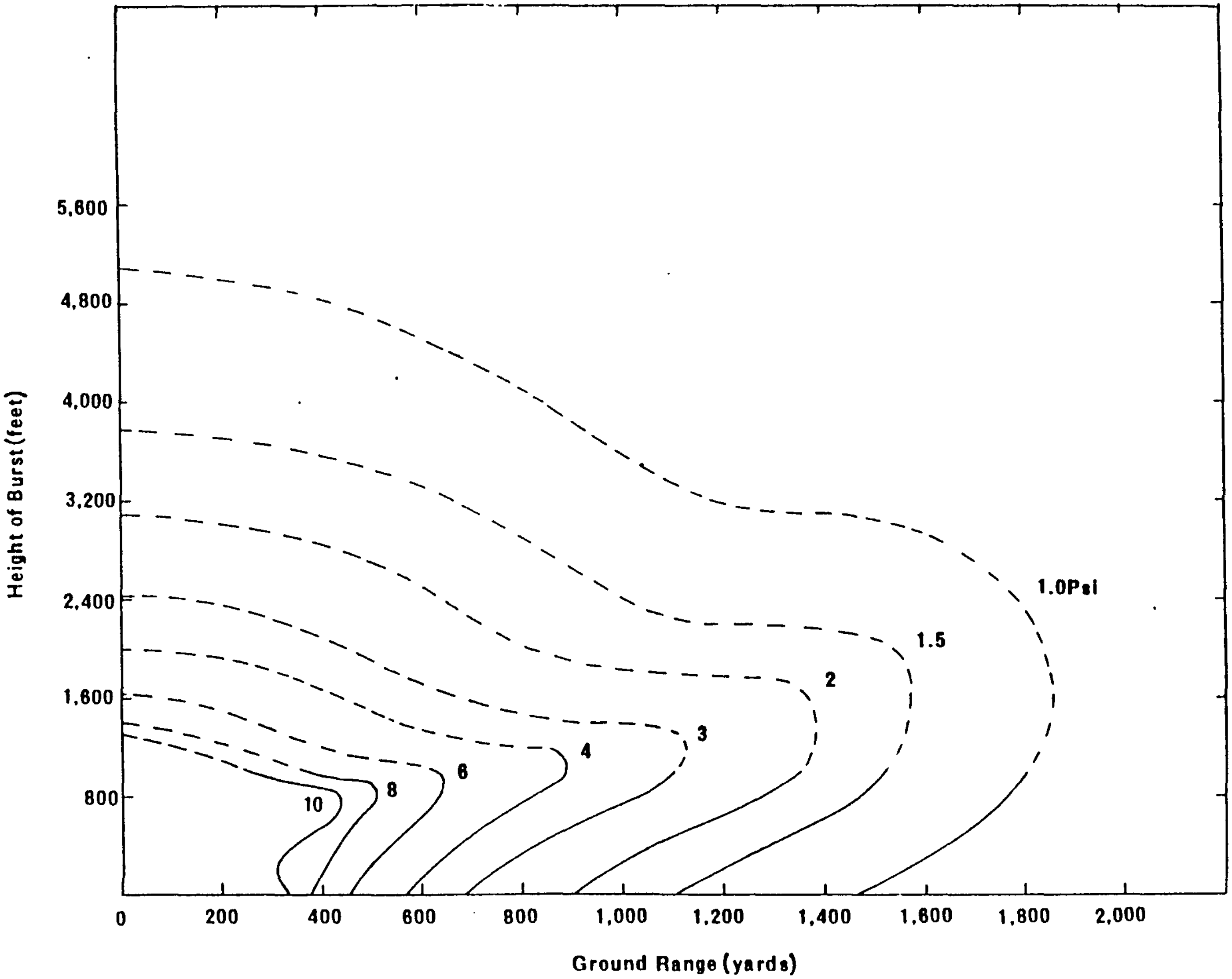


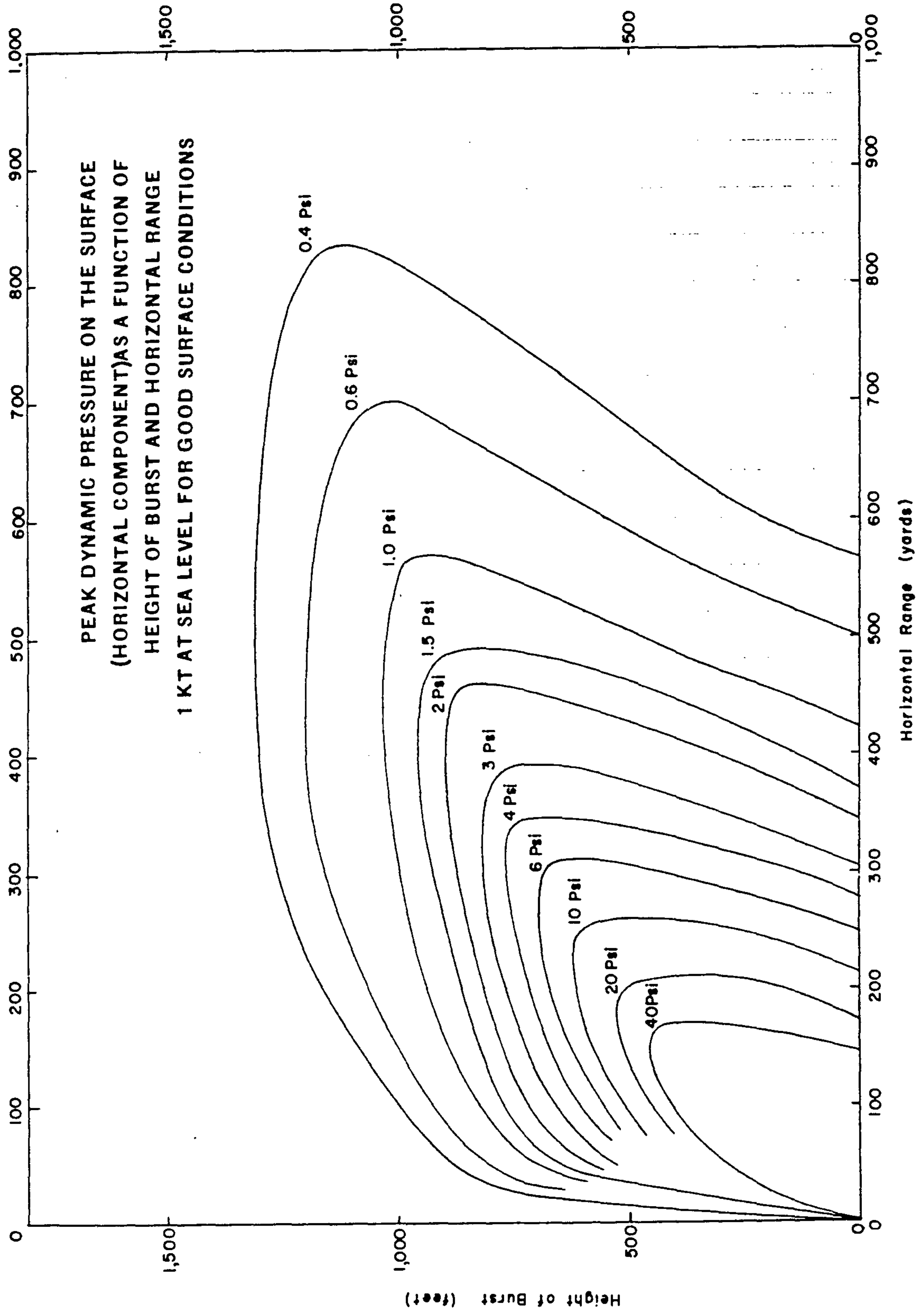
PEAK OVERPRESSURE ON THE SURFACE AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

1 KT AT SEA LEVEL FOR AVERAGE SURFACE CONDITIONS

FIGURE 2-10B

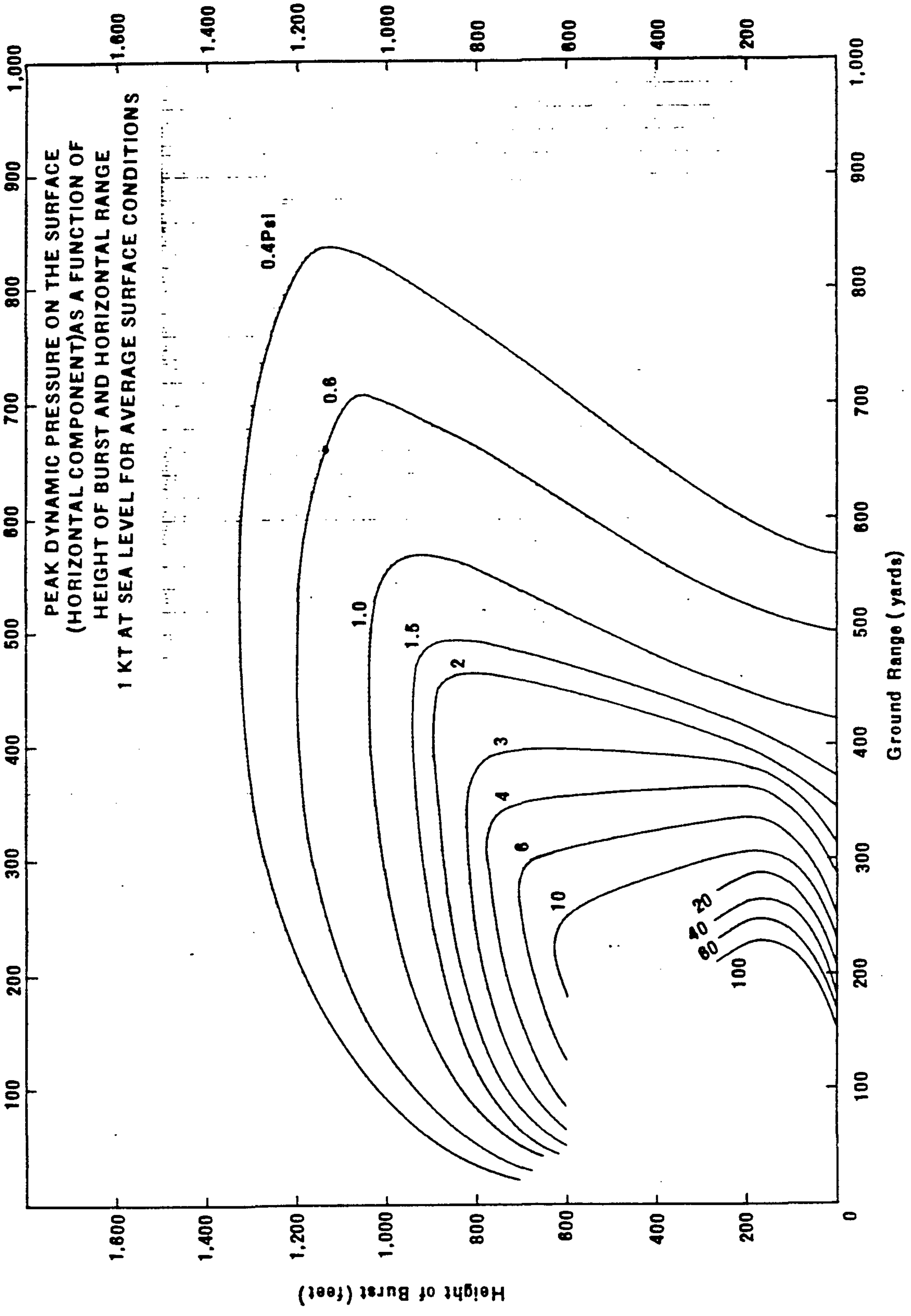
PEAK OVERPRESSURES ON THE SURFACE
AS A FUNCTION OF HEIGHT OF BURST AND HORIZONTAL RANGE
1 KT AT SEA LEVEL FOR AVERAGE SURFACE CONDITIONS



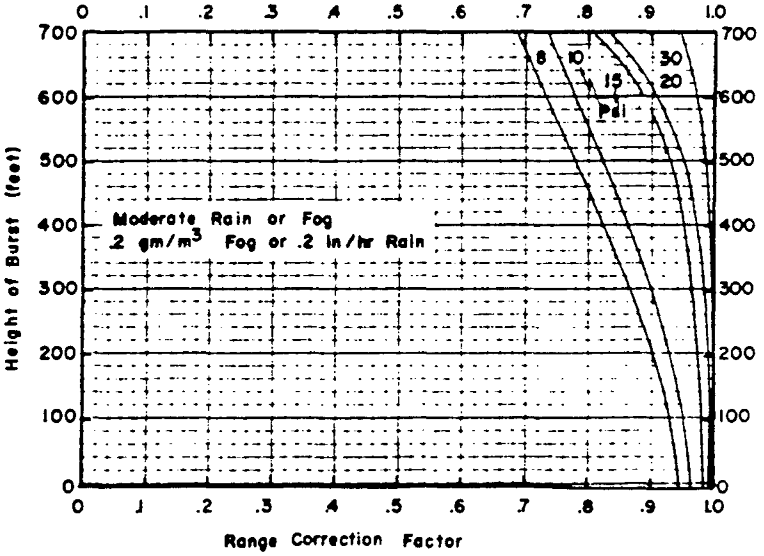


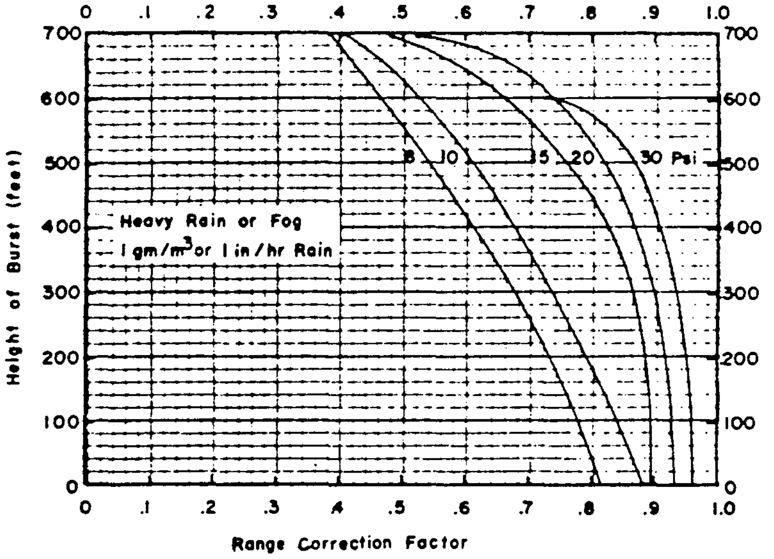
PEAK DYNAMIC PRESSURE ON THE SURFACE (HORIZONTAL COMPONENT)AS A FUNCTION OF HEIGHT OF BURST AND HORIZONTAL RANGE 1 KT AT SEA LEVEL FOR GOOD SURFACE CONDITIONS

FIGURE 2-13



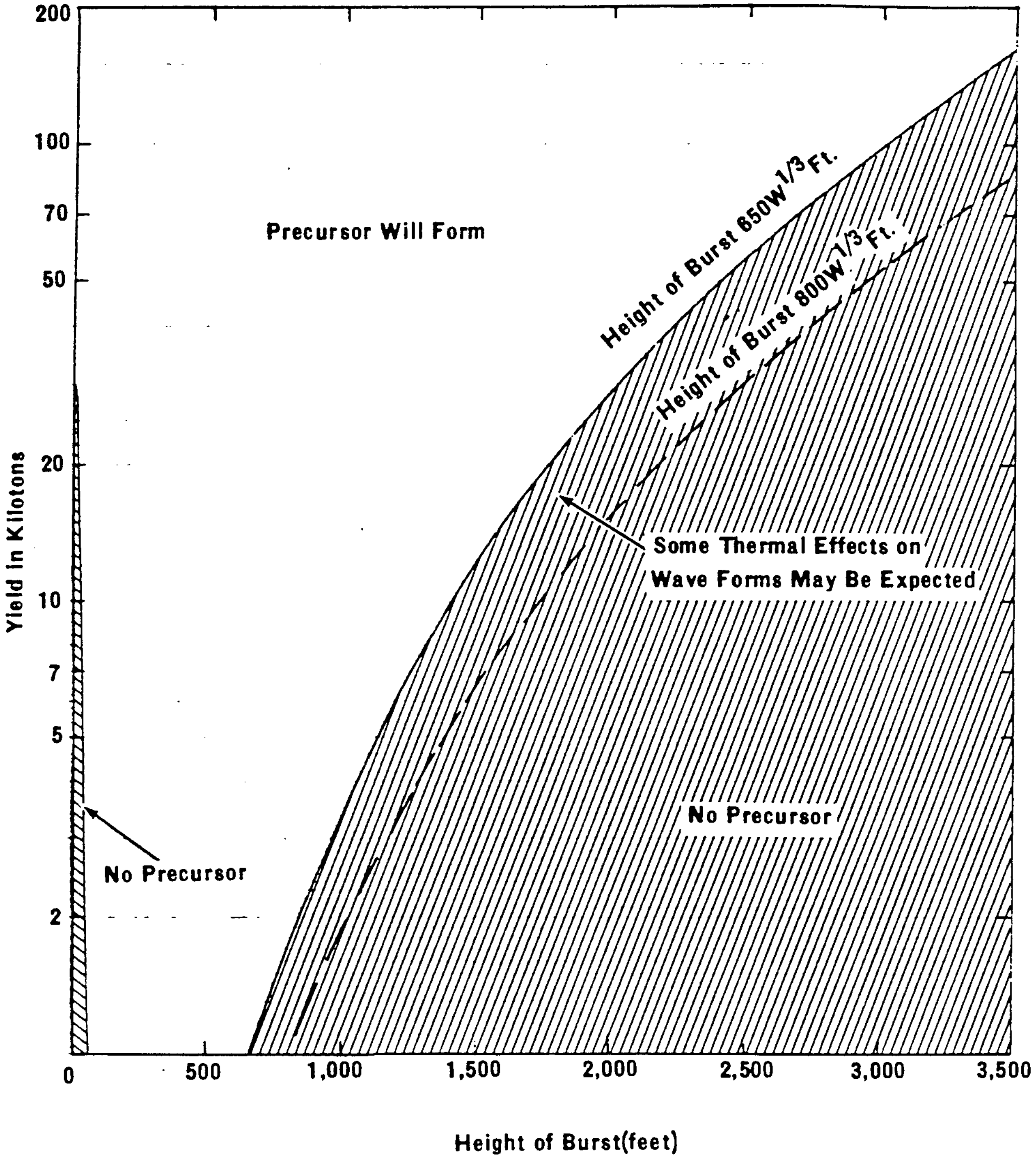
PEAK DYNAMIC PRESSURE ON THE SURFACE (HORIZONTAL COMPONENT) AS A FUNCTION OF HEIGHT OF BURST AND HORIZONTAL RANGE 1 KT AT SEA LEVEL FOR AVERAGE SURFACE CONDITIONS





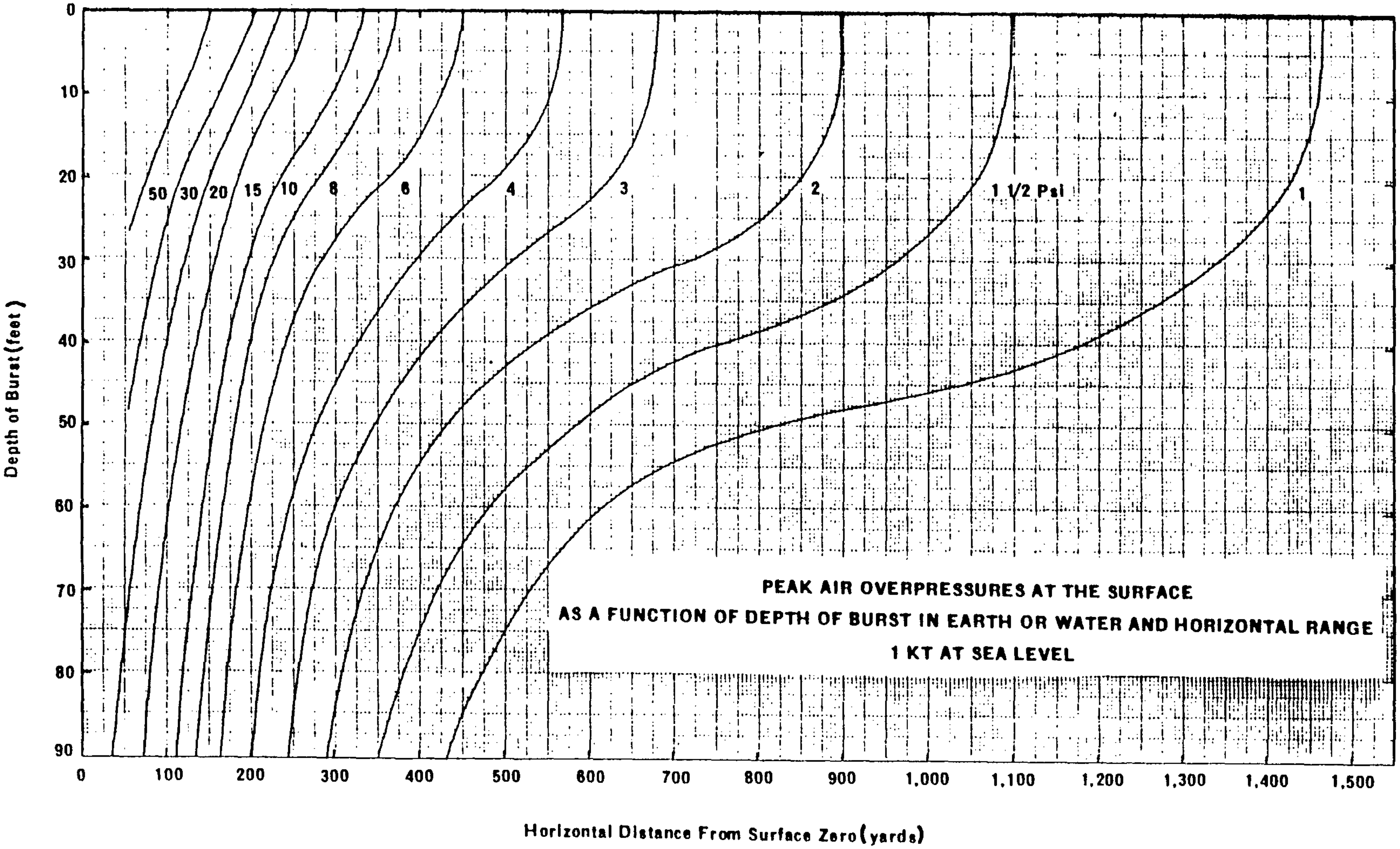
RAIN OR FOG EFFECTS ON PEAK OVERPRESSURE
AS A FUNCTION OF HEIGHT OF BURST
FOR 1 KT AT SEA LEVEL

CRITERIA FOR PRECURSOR FORMATION(AVERAGE SURFACE CONDITIONS)



~~CONFIDENTIAL~~

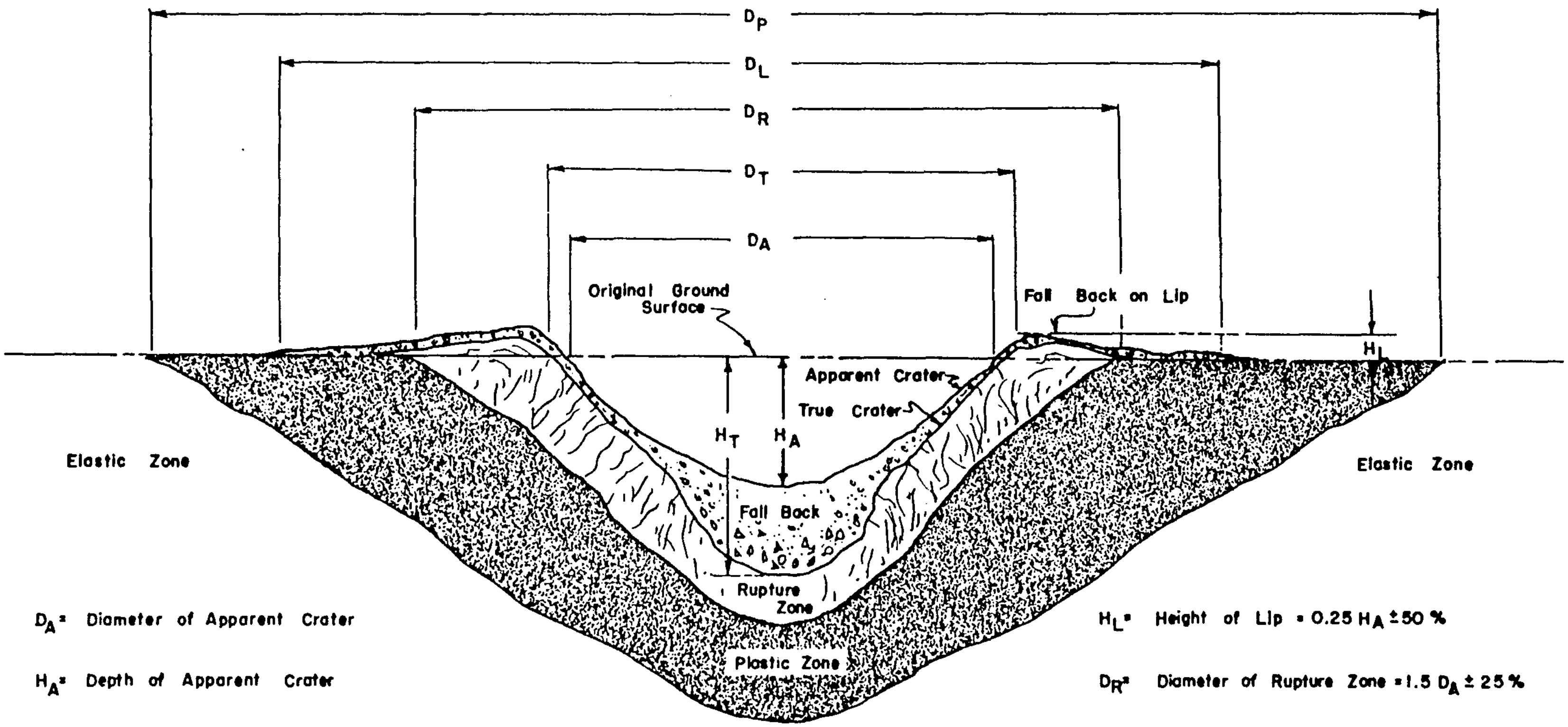
FIGURE 2-18



PEAK AIR OVERPRESSURES AT THE SURFACE
AS A FUNCTION OF DEPTH OF BURST IN EARTH OR WATER AND HORIZONTAL RANGE
1 KT AT SEA LEVEL

~~CONFIDENTIAL~~

CRATER PROFILE



D_A = Diameter of Apparent Crater

H_A = Depth of Apparent Crater

D_T = Diameter of True Crater

H_T = Depth of True Crater

D_L = Diameter of Lip = $2.0 D_A \pm 25\%$

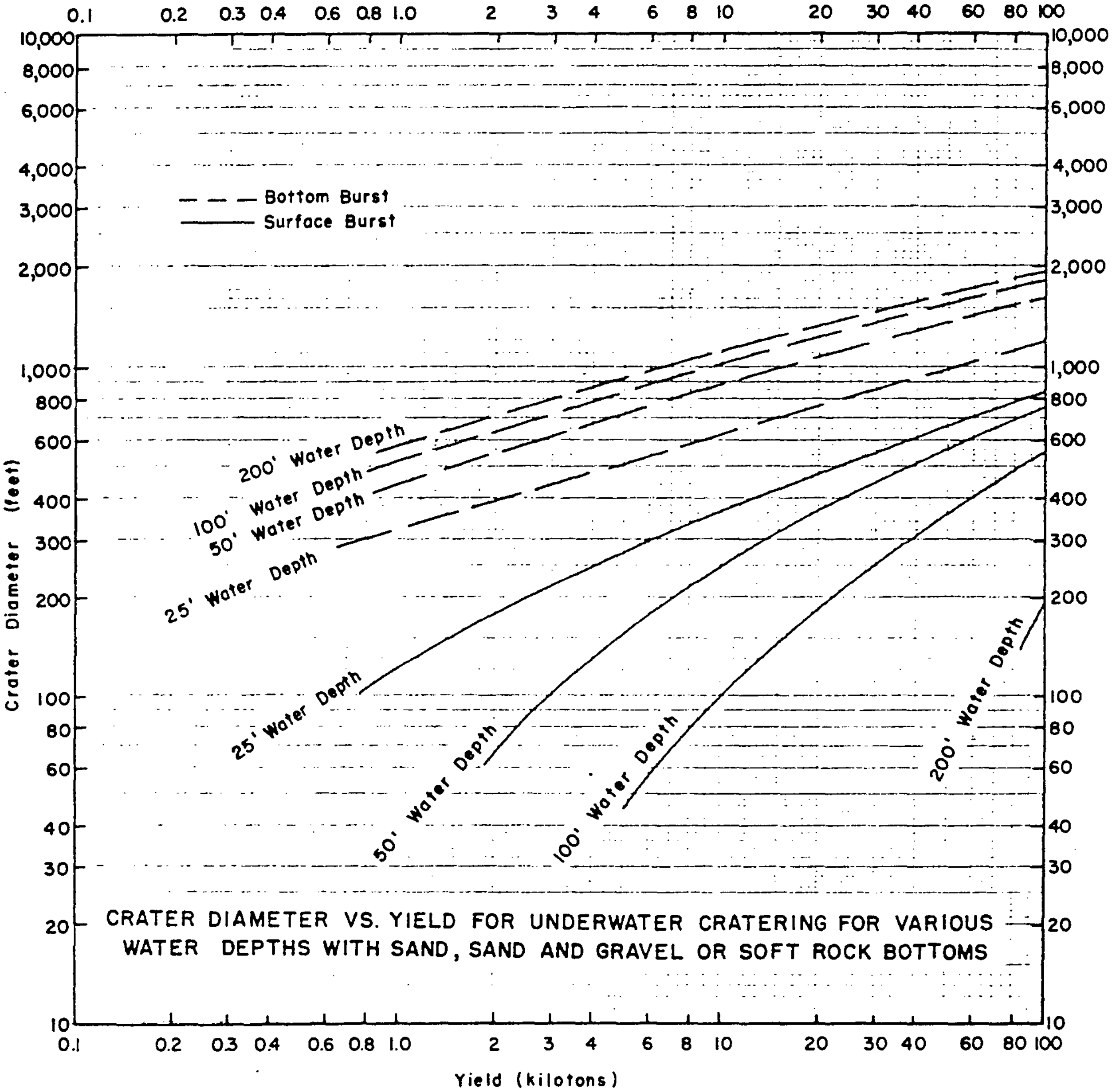
H_L = Height of Lip = $0.25 H_A \pm 50\%$

D_R = Diameter of Rupture Zone = $1.5 D_A \pm 25\%$

D_P = Diameter of Plastic Zone = $3 D_A \pm 50\%$

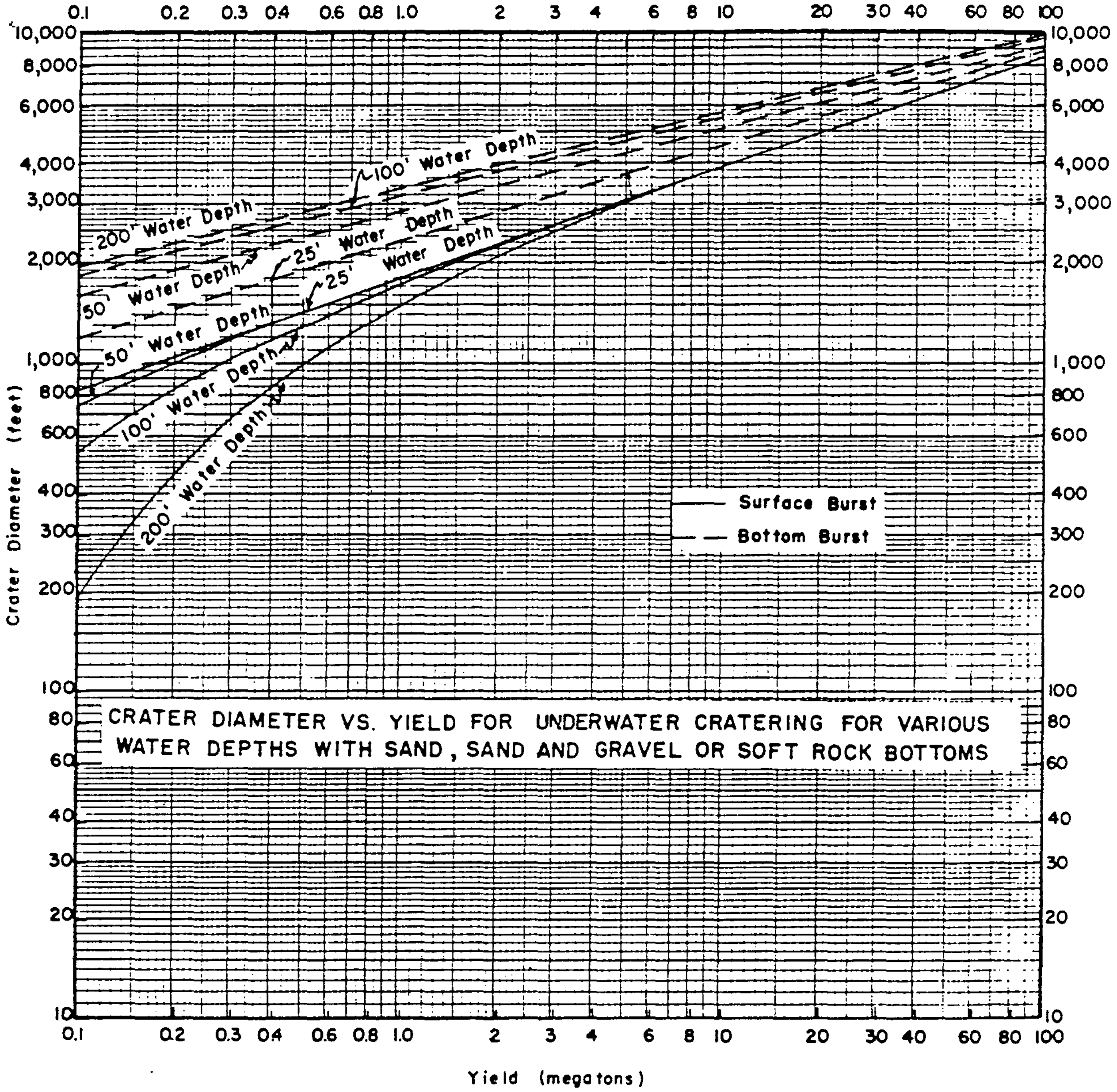
V_C = Volume of Apparent Crater = $\frac{\pi D_A^2 H_A}{8}$

(Assumed Paraboloid)

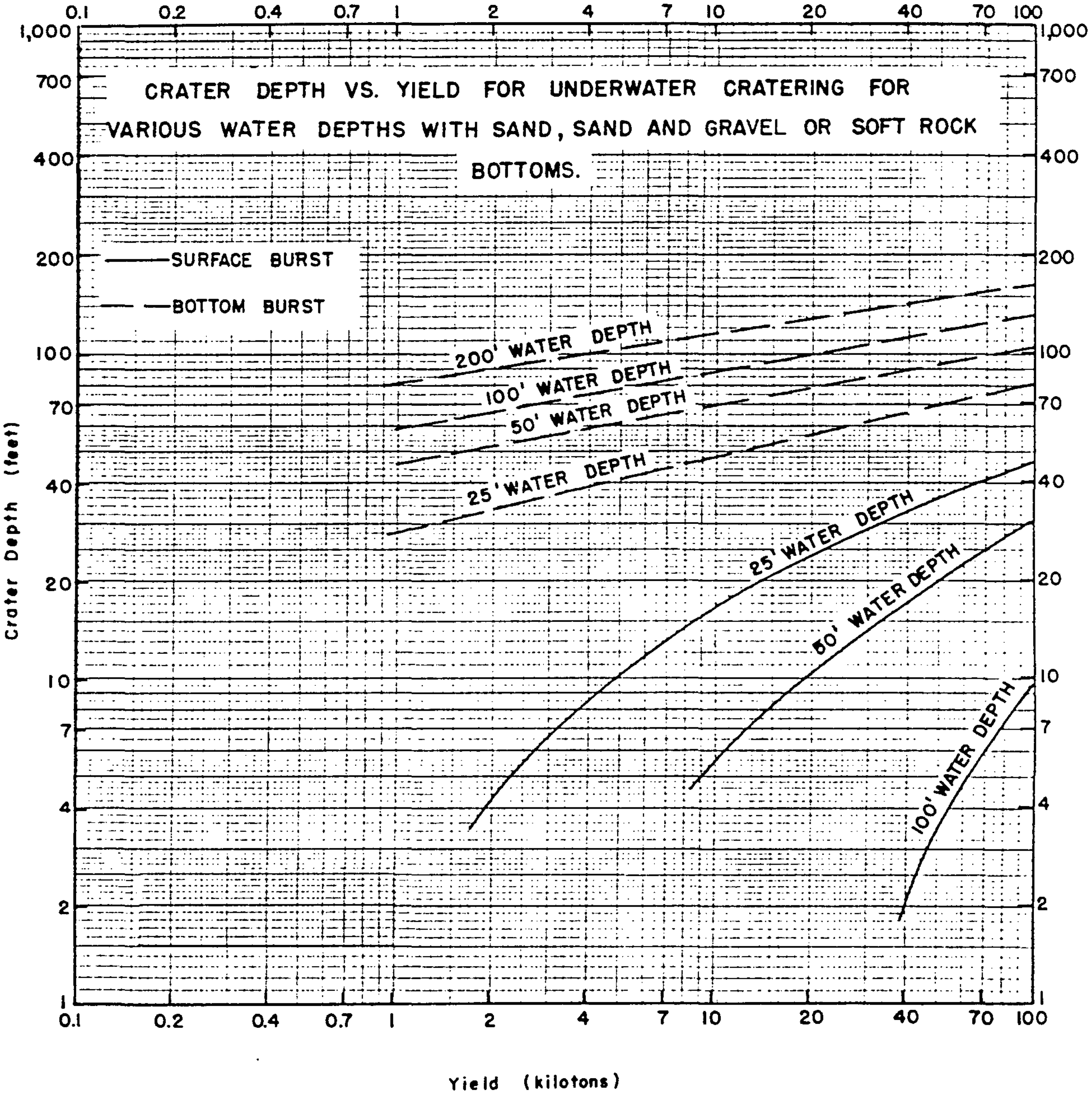


CRATER DIAMETER VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS

FIGURE 2-24B



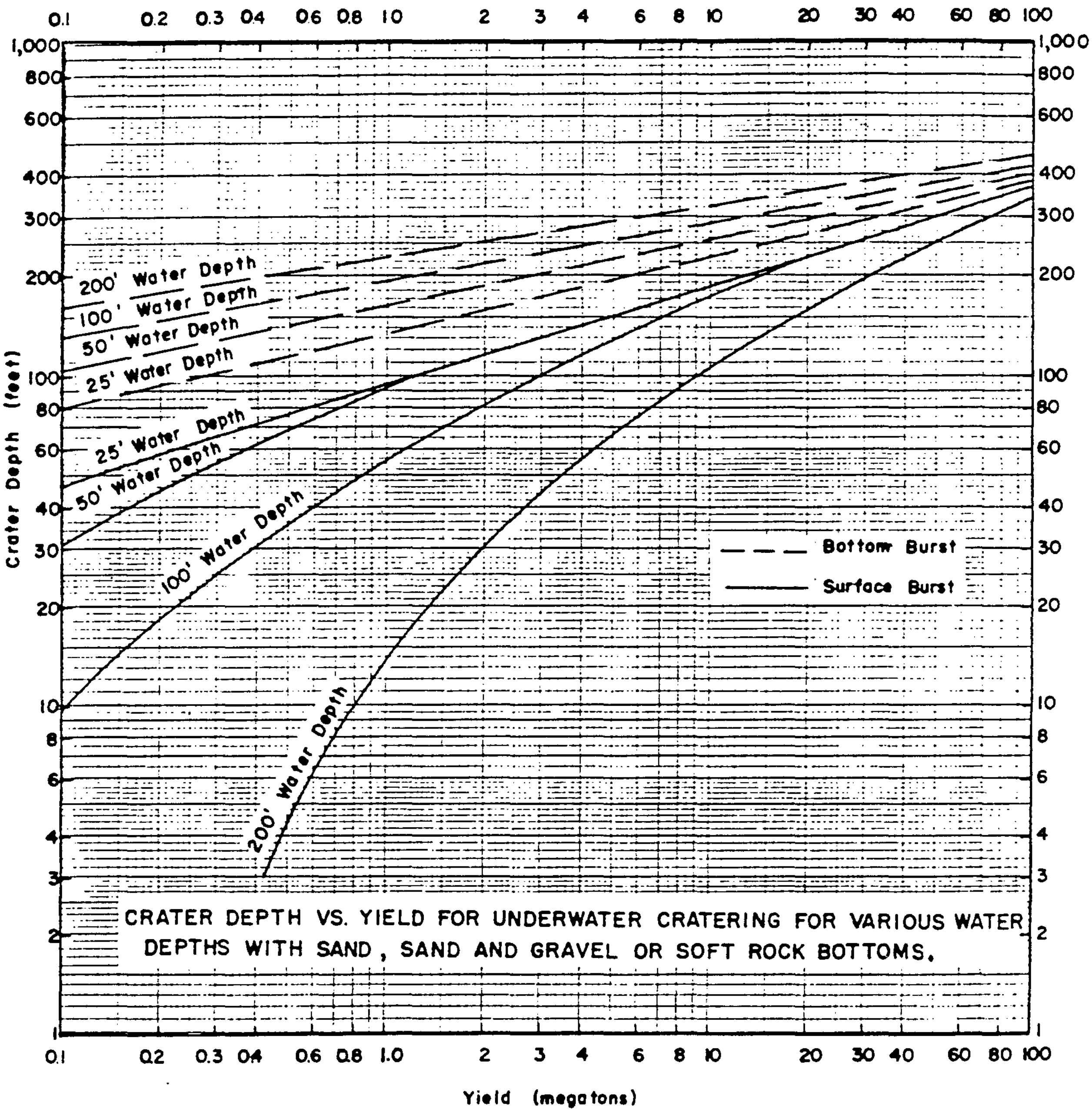
CRATER DIAMETER VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS


CRATER DEPTH VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS.
——SURFACE BURST
— —BOTTOM BURST
200' WATER DEPTH
100' WATER DEPTH
50' WATER DEPTH
25' WATER DEPTH
25' WATER DEPTH
50' WATER DEPTH
100' WATER DEPTH
Crater Depth (feet)
Yield (kilotons)
0.1
0.2
0.4
0.7
1
2
4
7
10
20
40
70
100
1,000
700
400
200
100
70
40
20
10
7
4
2
1

✓

~~CONFIDENTIAL~~

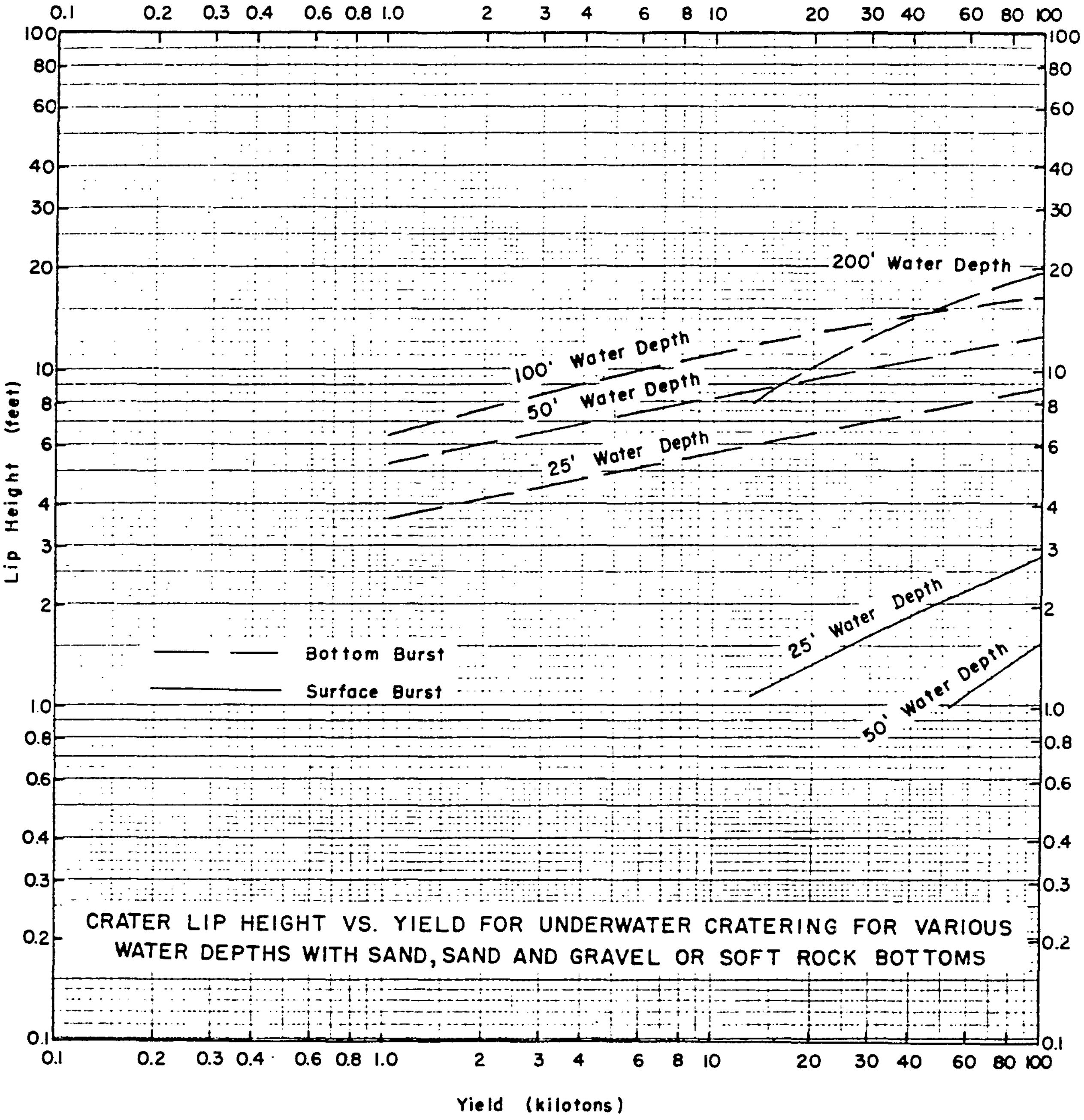
FIGURE 2-25B



CRATER DEPTH VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS.

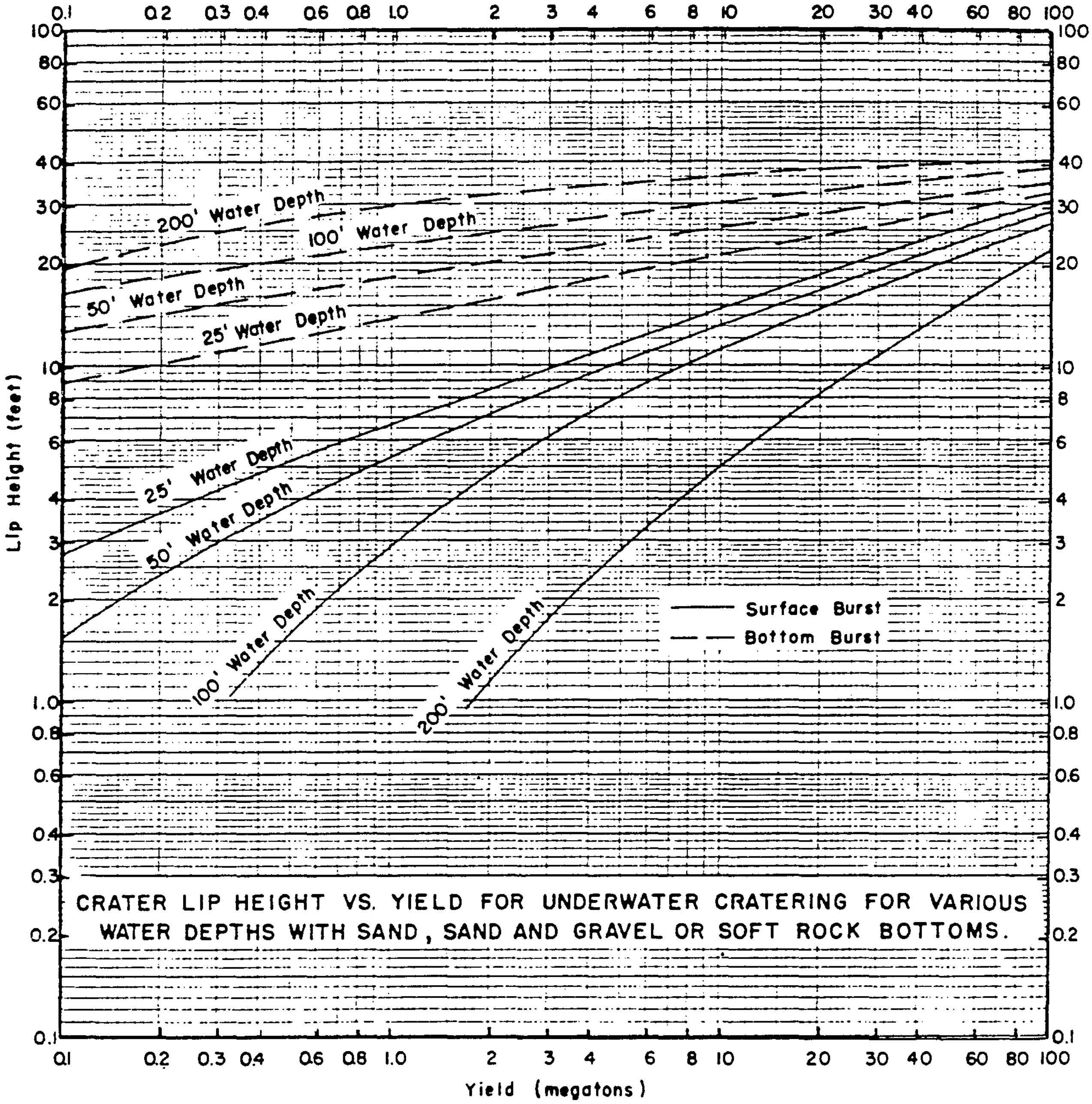
~~CONFIDENTIAL~~

FIGURE 2-26A



CRATER LIP HEIGHT VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS

FIGURE 2-26B



CRATER LIP HEIGHT VS. YIELD FOR UNDERWATER CRATERING FOR VARIOUS WATER DEPTHS WITH SAND, SAND AND GRAVEL OR SOFT ROCK BOTTOMS.

✓

FIGURE 2-28

PEAK AIR BLAST INDUCED GROUND ACCELERATION
VERTICAL COMPONENT Vs. PEAK OVERPRESSURE

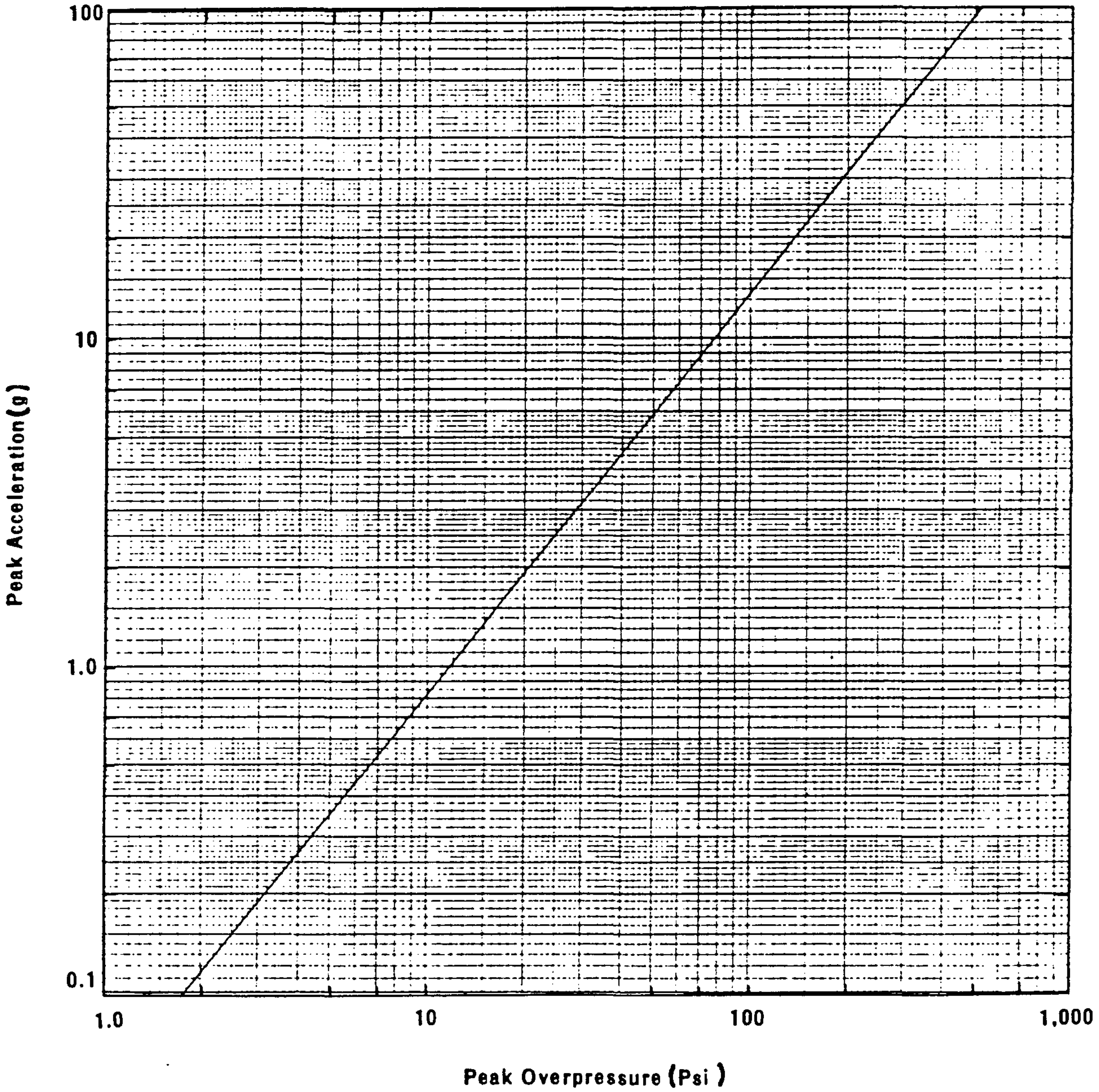


FIGURE 2-29A

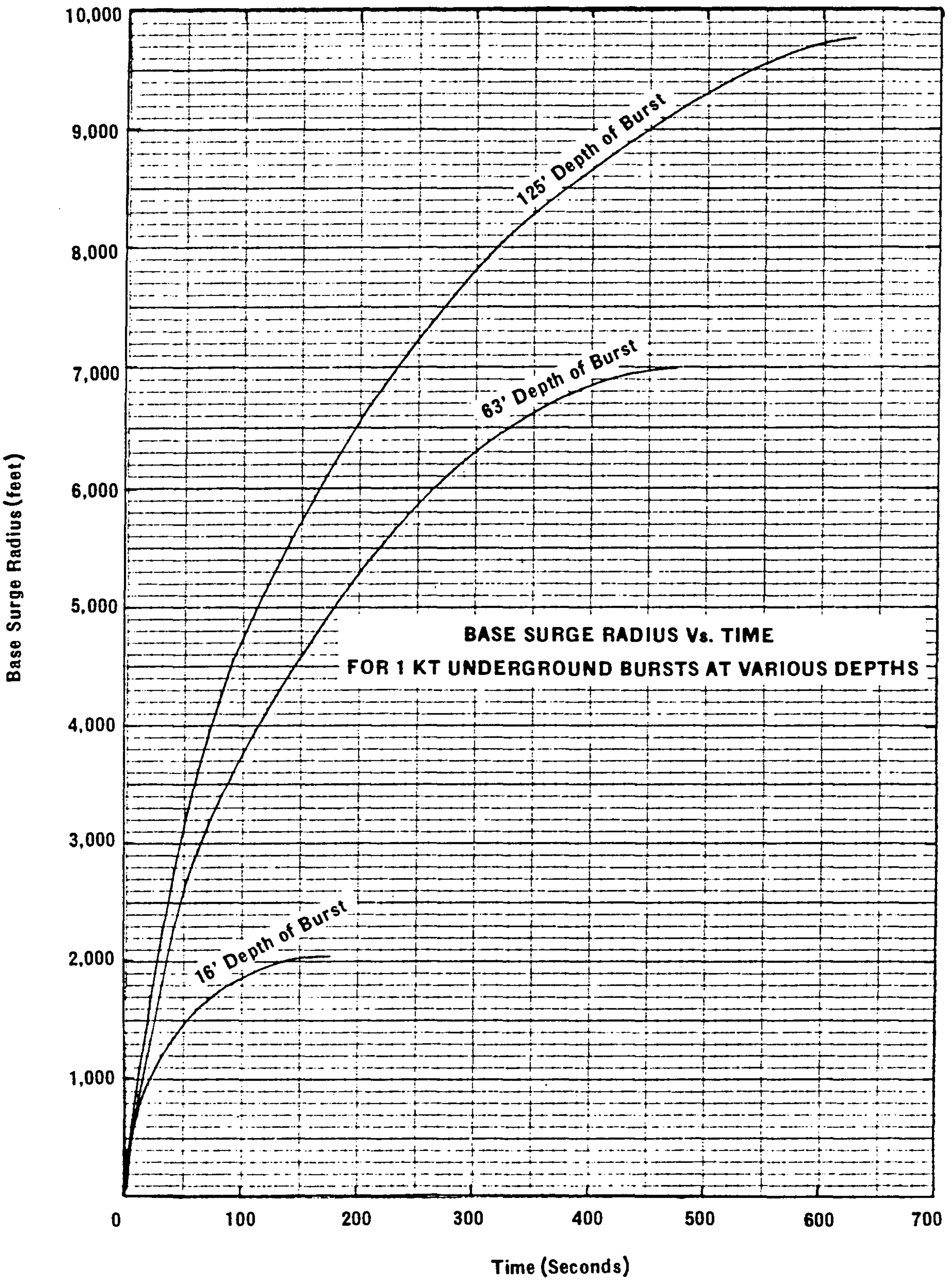
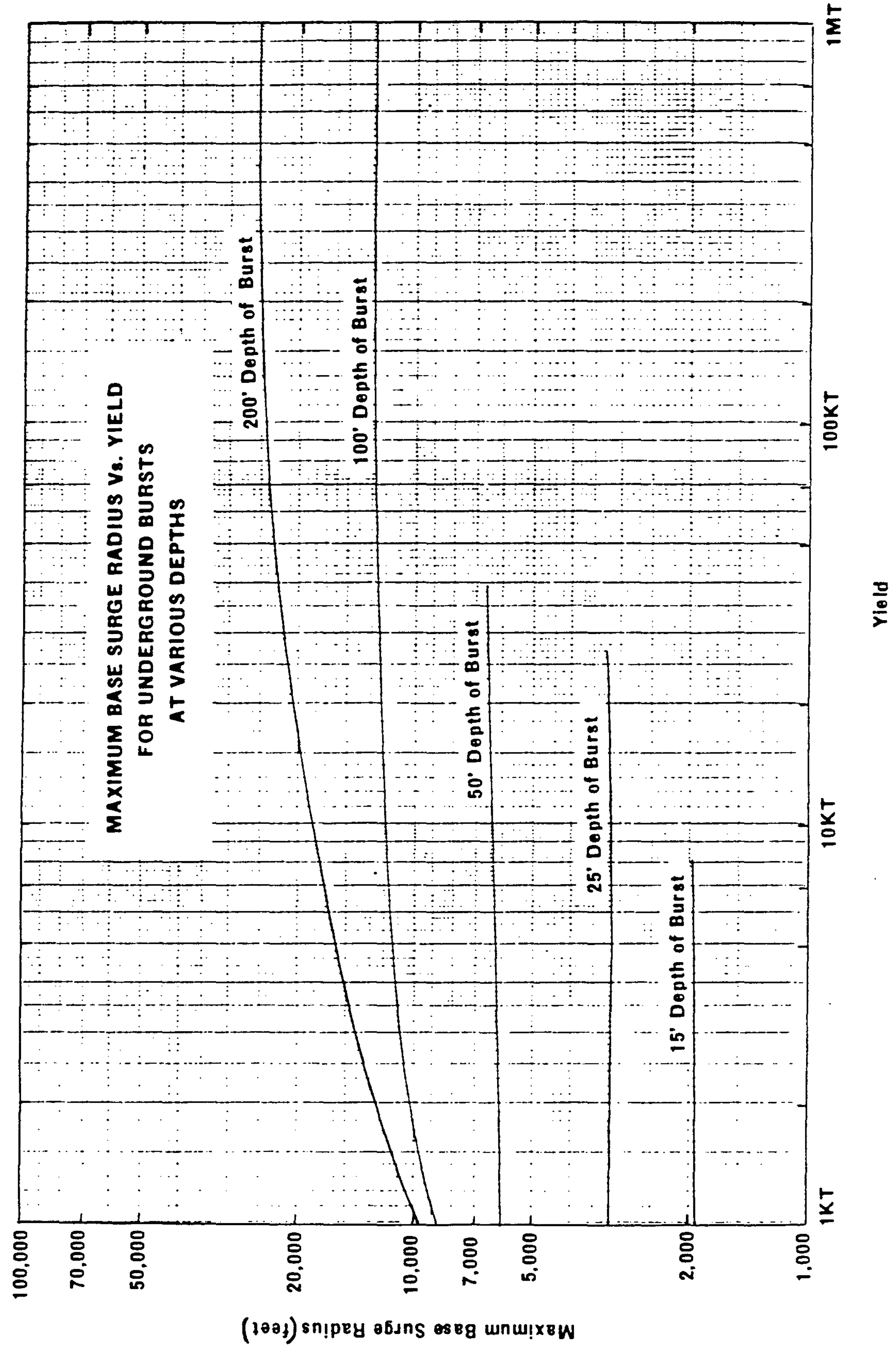

BASE SURGE RADIUS Vs. TIME FOR 1 KT UNDERGROUND BURSTS AT VARIOUS DEPTHS

FIGURE 2-29B



MAXIMUM BASE SURGE RADIUS Vs. YIELD FOR UNDERGROUND BURSTS AT VARIOUS DEPTHS

MAXIMUM WAVE HEIGHT FOR WATER BURSTS

Figure 2–34 gives the approximate maximum crest-to-trough wave heights vs. horizontal distance to be expected from surface and underwater bursts of 1 KT weapons. These may be scaled to other yields as explained below. For burst depths greater than 180 $W^{1/4}$ feet but less than 850 $W^{1/4}$ feet, a linear interpolation between the values from the above limiting cases will provide a satisfactory prediction. Below 850 $W^{1/4}$ feet, the wave height is expected to decrease almost inversely with increasing depth.

Scaling. Use the following relations:

$$(a)\qquad \frac{W_1^{1/2}}{W_2^{1/2}}=\frac{h_1}{h_2},$$

where yield W_1 will give a wave height of h_1, and yield W_2 will give a corresponding wave height h_2 at the same scaled depth of burst.

$$(b)\qquad \frac{d_1}{d_2}=\frac{W_1^{1/4}}{W_2^{1/4}}=\frac{d_1'}{d_2'},$$

where yield W_1, burst at a depth d_1 in water of depth d_1', is equivalent to a burst of yield W_2 at a depth d_2 in water of depth d_2'.

Example.

Given: A 40 KT detonation at 450 feet in 1,500 feet of water.

Find: The expected maximum wave height at 10,000 yards from surface zero.

Solution: The corresponding burst depth for 1 KT is, from (*b*) above:

$$d_1=\frac{450}{(40)^{1/4}}=\frac{450}{2.5}=180 \text{ feet.}$$

The corresponding water depth for 1 KT is:

$$d_1'=\frac{1{,}500}{(40)^{1/4}}=\frac{1{,}500}{2.5}=600 \text{ feet.}$$

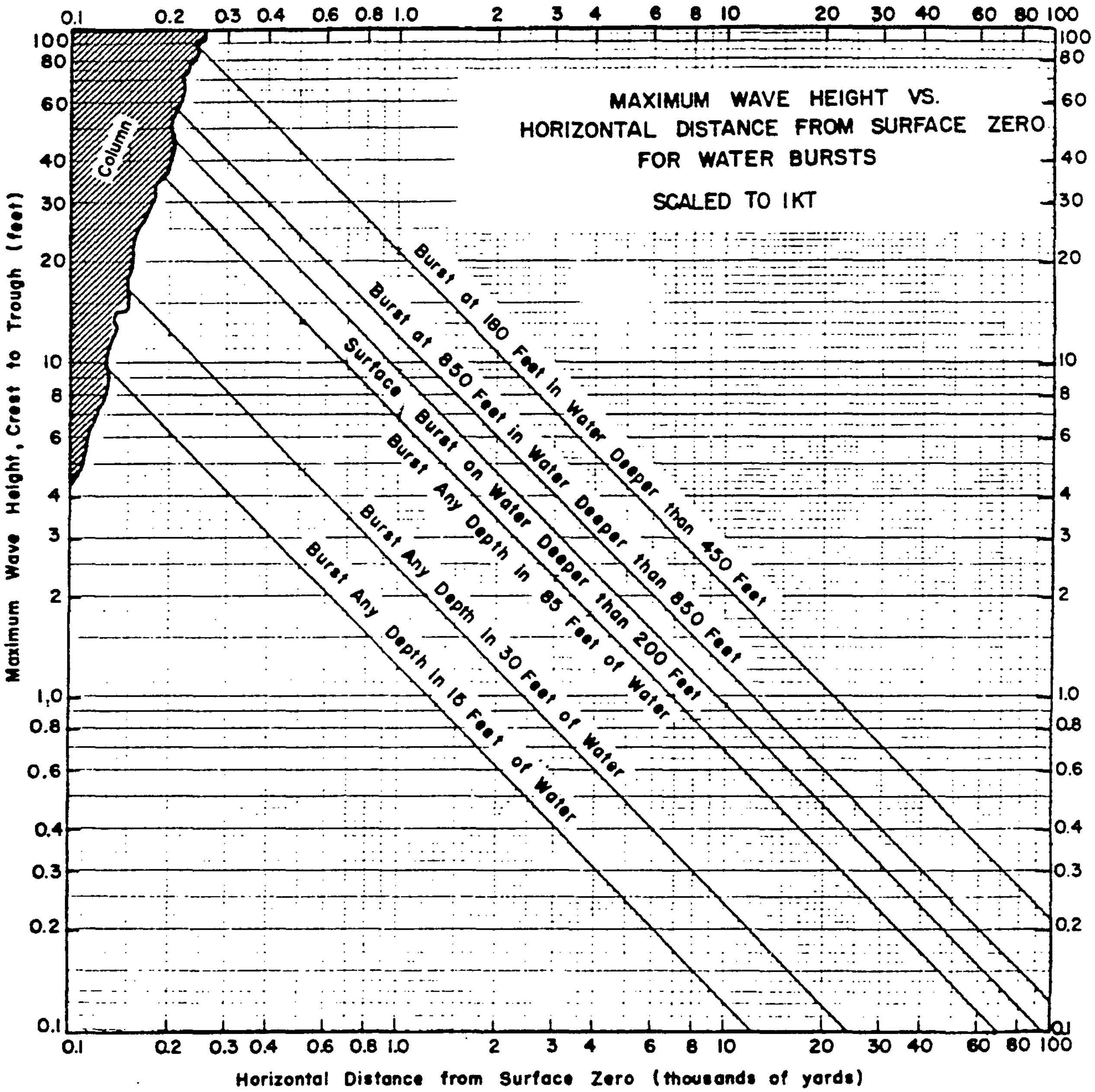
The curve of figure 2–34 for burst depth of 180 feet and water depths of 450 feet or greater is used. From this curve, the maximum wave height at 10,000 yards for a 1 KT burst is 2.2 feet. Therefore, for a 40 KT burst, the wave height at 10,000 yards is, from (*a*) above:

$h_2=(2.2)\times(40)^{1/2}=(2.2)\times(6.3)=14$ (± 4) feet. *Answer.*

Reliability. The wave heights obtained from figure 2–34 are estimated to be reliable within ±30 percent.

Related material.

See paragraph 2.3*b*.


MAXIMUM WAVE HEIGHT VS.
HORIZONTAL DISTANCE FROM SURFACE ZERO
FOR WATER BURSTS
SCALED TO 1KT
Column
Burst at 180 Feet in Water Deeper than 450 Feet
Burst at 850 Feet in Water Deeper than 850 Feet
Surface Burst on Water Deeper than 200 Feet
Burst Any Depth in 85 Feet of Water
Burst Any Depth in 30 Feet of Water
Burst Any Depth in 15 Feet of Water
Maximum Wave Height, Crest to Trough (feet)
Horizontal Distance from Surface Zero (thousands of yards)
0.1
0.2
0.3
0.4
0.6
0.8
1.0
2
3
4
6
8
10
20
30
40
60
80
100

BASE SURGE FOR UNDERWATER BURSTS

Figure 2–35A gives the expected radial growth of the water base surge as a function of time after detonation for a 1 KT weapon at various depths of burst. Figure 2–35B gives the expected maximum base surge radius as a function of yield for several specific depth of burst conditions. The maximum base surge is developed from a weapon detonated at approximately the venting depth (250 $W^{1/4}$ ft.). For very shallow depths of burst, less than 10 $W^{1/3}$ feet, the occurrence of a base surge is improbable. Proximity of the bottom to the point of detonation has little effect upon the production of the base surge. For depths of burst between the limits 10 $W^{1/3}$ and 250 $W^{1/4}$ feet, the diameter of the water column producing the base surge is approximately one fourth of the resultant surge radius. With depths of burst below the venting depth of 250 $W^{1/4}$ feet, no such simple relation of the column or plume to the resultant surge exists. Little data or theory is available for base surge predictions at deep depths. A prediction can be made, however, by linear interpolation between the base surge radius of a burst at venting depth and one at a deep scaled depth (650 $W^{1/3}$ feet). A prediction thus made represents the maximum base-surge which could be expected.

Radii obtained from figures 2–35A and 2–35B assume "no wind" conditions. To compute upwind or downward base surge radii for a specific time after detonation, add the distance traveled by the wind up to this time to the "no wind" base surge radius to obtain the downwind base surge radius, or subtract to obtain the upwind base surge radius.

Scaling. Depth of burst and the accompanying maximum radius of the base surge scale as the cube root of yield for depths of burst between 25 $W^{1/3}$ and 250 $W^{1/4}$, or:

$$\frac{h_1}{h_2}=\frac{r_1}{r_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where h_1 and r_1 are depth of burst and base surge radius for yield W_1, and h_2 and r_2 are the corresponding depth of burst and base surge radius for yield W_2.

Time to complete a given percentage of total radial growth of the base surge scales as the one-sixth power of the yield for the same scaled depth of burst, or:

$$\frac{t_1}{t_2}=\frac{W_1^{1/6}}{W_2^{1/6}},$$

where t_1=time to complete a given percentage of total radial growth for yield W_1 and t_2=the corresponding time to complete the same percentage of total radial growth for yield W_2.

Time to reach the maximum base surge radius from a detonation at venting depth or less may also be computed by:

$$t_{max}=2.25r^{1/2}$$

where t_{max}=time to the maximum base surge radius in seconds,

and r=maximum base surge radius in feet.

Examples.

(1) *Given:* A 10 KT detonation at a depth of 150 feet below the water surface.

Find:

(*a*) The maximum base surge radius.

(*b*) Time to maximum base surge radius.

(*c*) The expected base surge radius 1 minute after detonation.

Solution:

(*a*) The maximum base surge radius is read directly from figure 2–35B as 7,200 feet. *Answer.*

(*b*) The venting depth is 250 $W^{1/4}=440$ feet. Since the depth of burst is less than venting, the simplified formula for time to maximum may be used. The time of maximum base surge radius is $t_{max}=2.25\ (7{,}200)^{1/2}=190$ seconds. *Answer.*

(*c*) A 10 KT detonation of 150 feet depth will complete the same percentage of its total radial growth in 60 seconds as a 1 KT detonation will complete at a corresponding scaled time and depth. Using the scaling above, the corresponding depth of burst for 1 KT is—

$$h_1=\frac{W_1^{1/3}\times h_2}{W_2^{1/3}}=\frac{1\times 150}{(10)^{1/3}}=70 \text{ ft.}$$

The time that a 1 KT weapon burst at a depth of 70 feet will have completed the same percentage of its growth that a 10 KT burst will have completed in 60 seconds is:

$$t_1=\frac{t_2\times W_1^{1/6}}{W_2^{1/6}}=\frac{60\times 1}{(10)^{1/6}}=41 \text{ seconds.}$$

From figure 2-35A the maximum surge for a 1 KT at 70 feet is 3,400 feet and at 41 seconds the surge has a radius of 2,000 feet. Thus it has completed 60 percent of its growth. A 10 KT detonation at a depth of 150 feet will then complete in one minute 60 percent of its maximum radial growth or—

$0.60\times 7{,}200=4{,}300$ feet. *Answer.*

(2) *Given:* A 30 KT detonation at a depth of 1,000 feet below the water surface.

Find: The maximum base surge radius.

Solution: The venting depth for a 30 KT detonation is approximately 250 $W^{1/4}$ or 600 feet. Little data is available upon which to predict the maximum base surge radius at depths exceeding this. Hence, a prediction must be made by linear interpolation between the venting depth, 600 feet, and a depth of 650 $W^{1/3}$ or 2,000 feet.

From figure 2-35B the maximum base surge radius at venting depth is 12,000 feet. At 650 $W^{1/3}$ the maximum base surge radius is 7,000 feet. By interpolation the maximum base surge radius for a 30 KT detonation at 1,000 feet is

$$12{,}000-\left(\frac{400}{1{,}400}\times 5{,}000\right)=10{,}600 \text{ ft.}$$

Answer.

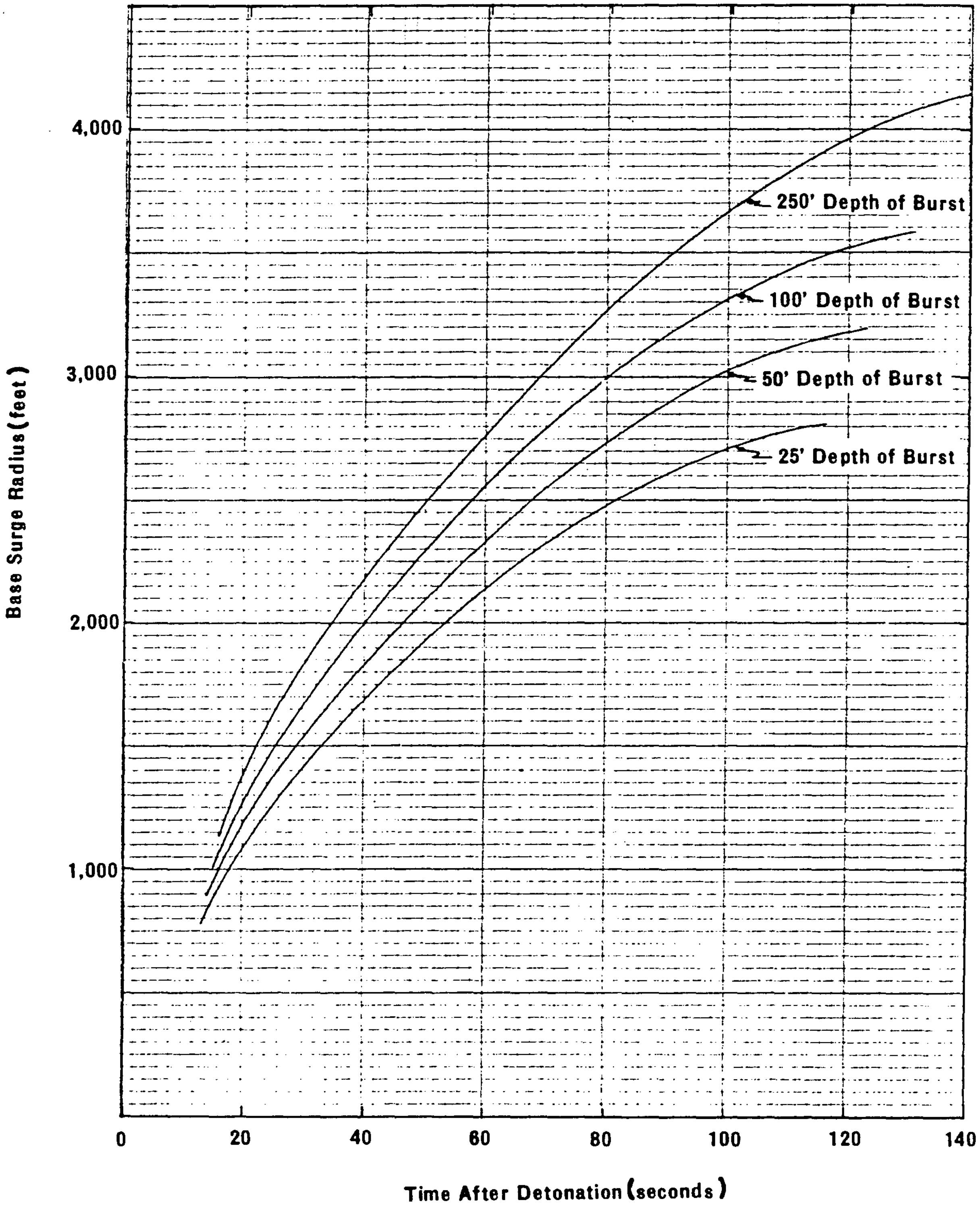
Reliability. Figures 2-35A and 2-35B are based upon limited full scale and extensive reduced scale testing.

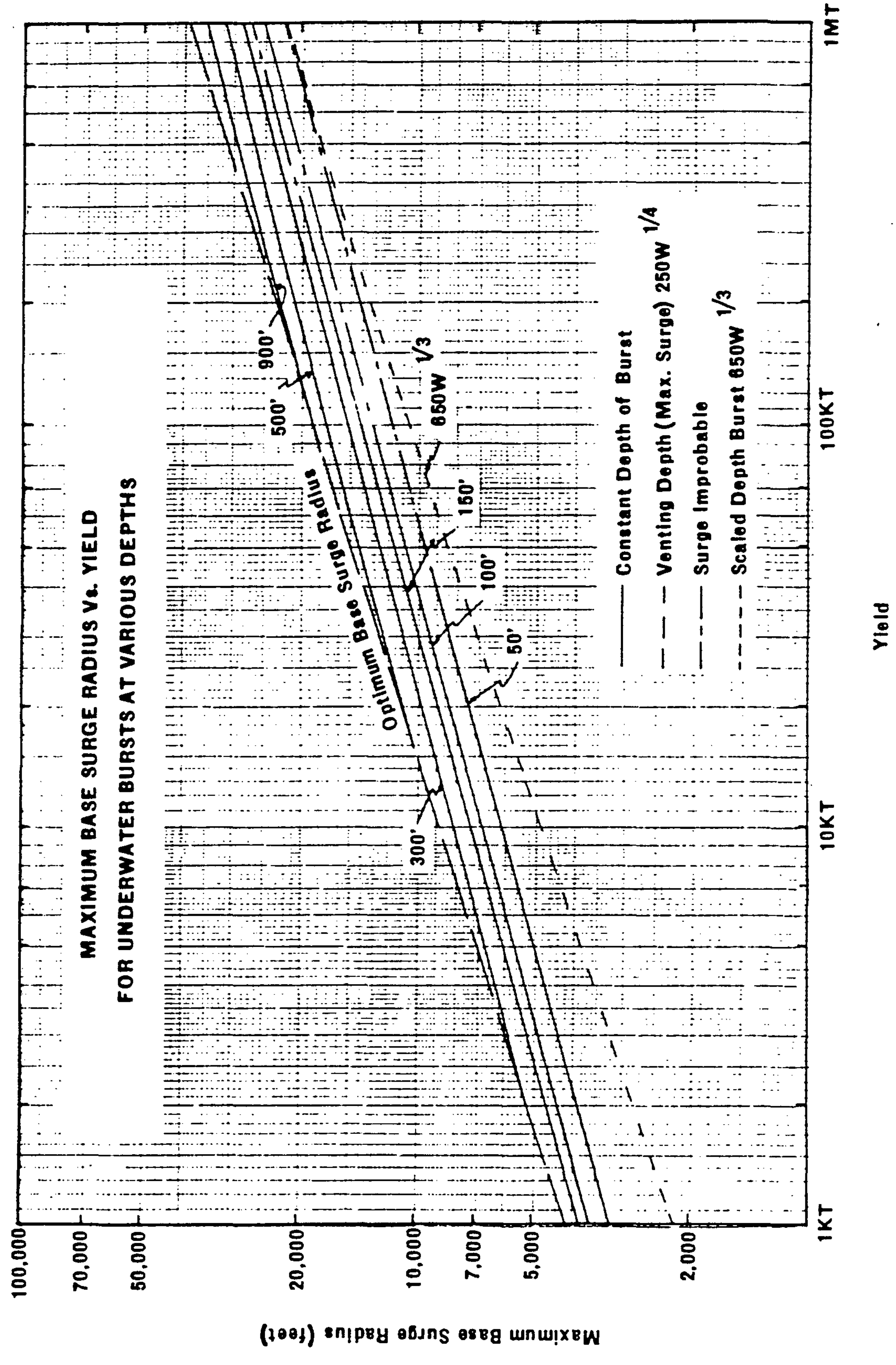
Related material.

See paragraph 2.3*c*.

FIGURE 2-35A

BASE SURGE RADIUS Vs. TIME
FOR 1 KT UNDERWATER BURSTS AT VARIOUS DEPTHS





MAXIMUM BASE SURGE RADIUS Vs. YIELD FOR UNDERWATER BURSTS AT VARIOUS DEPTHS

ATMOSPHERIC TRANSMISSIVITY

Figures 3–5A and 3–5B give the atmospheric transmissivity versus slant range for three sets of atmospheric conditions for both air and surface burst weapons. These curves are presented for illustrative purposes, since these were used to derive the radiant exposure vs. slant range curves of figures 3–6A and 3–6B.

The differences between the air burst and surface burst curves are caused by the difference in apparent radiating temperatures (when viewed from the ground) and the difference in geometrical configuration of the two types of burst. The three sets of atmospheric conditions represented are:

50 mile visibility and 5 gm/m³ water vapor.

10 mile visibility and 10 gm/m³ water vapor.

2 mile visibility and 25 gm/m³ water vapor.

It is believed that these conditions pertain to the extreme and the average atmospheres which occur naturally.

Reference can be made to the atmospheric water vapor concentration curves in appendix I to ascertain under what conditions of relative humidity and ambient temperature a particular water vapor concentration will occur.

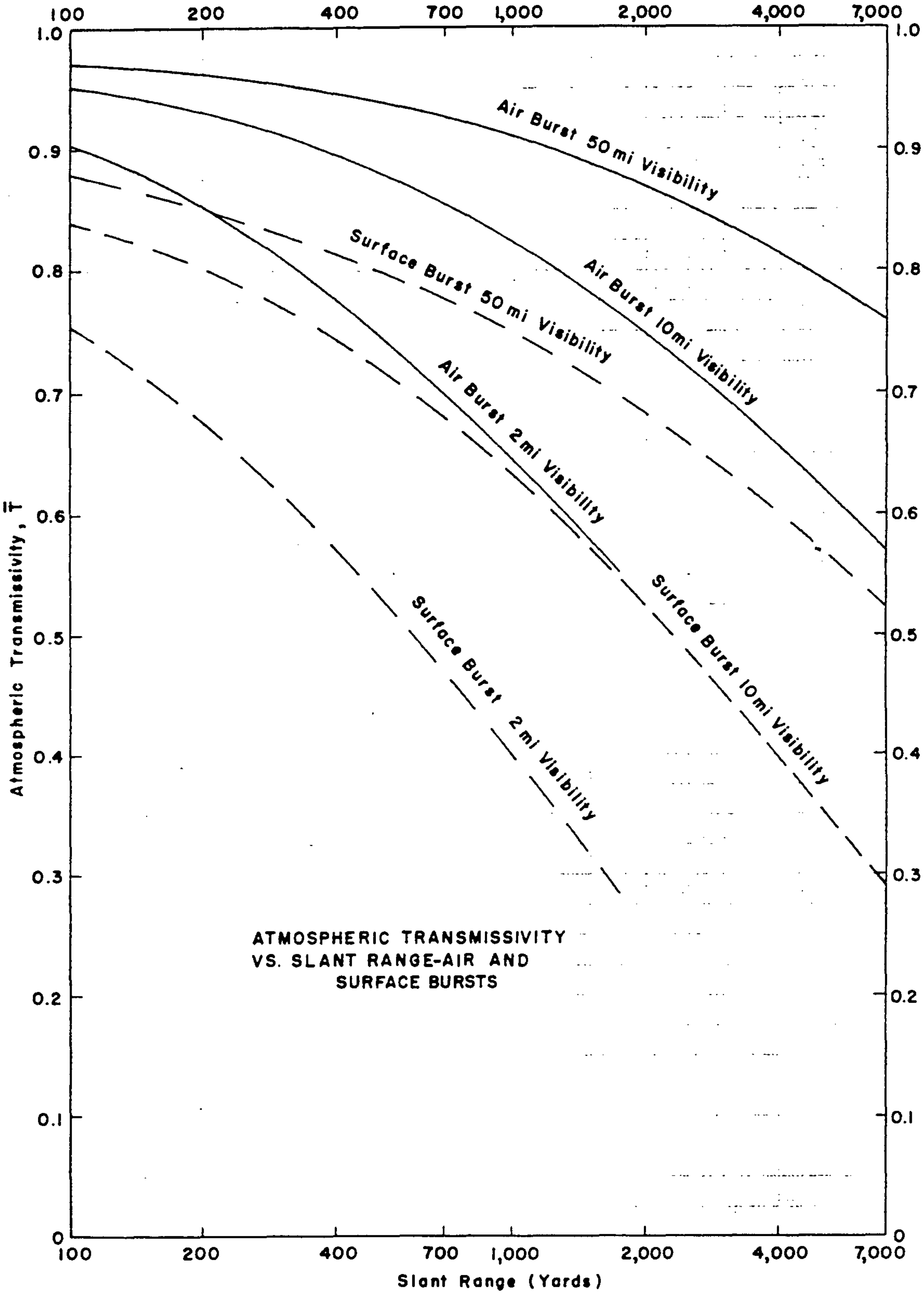
Reliability. The curves of figures 3–5A and 3–5B have not been verified at ranges beyond one-half the visibility and, as a result, are subject to considerably reduced reliability beyond these ranges.

Related material.

See paragraph 3.3*b*.

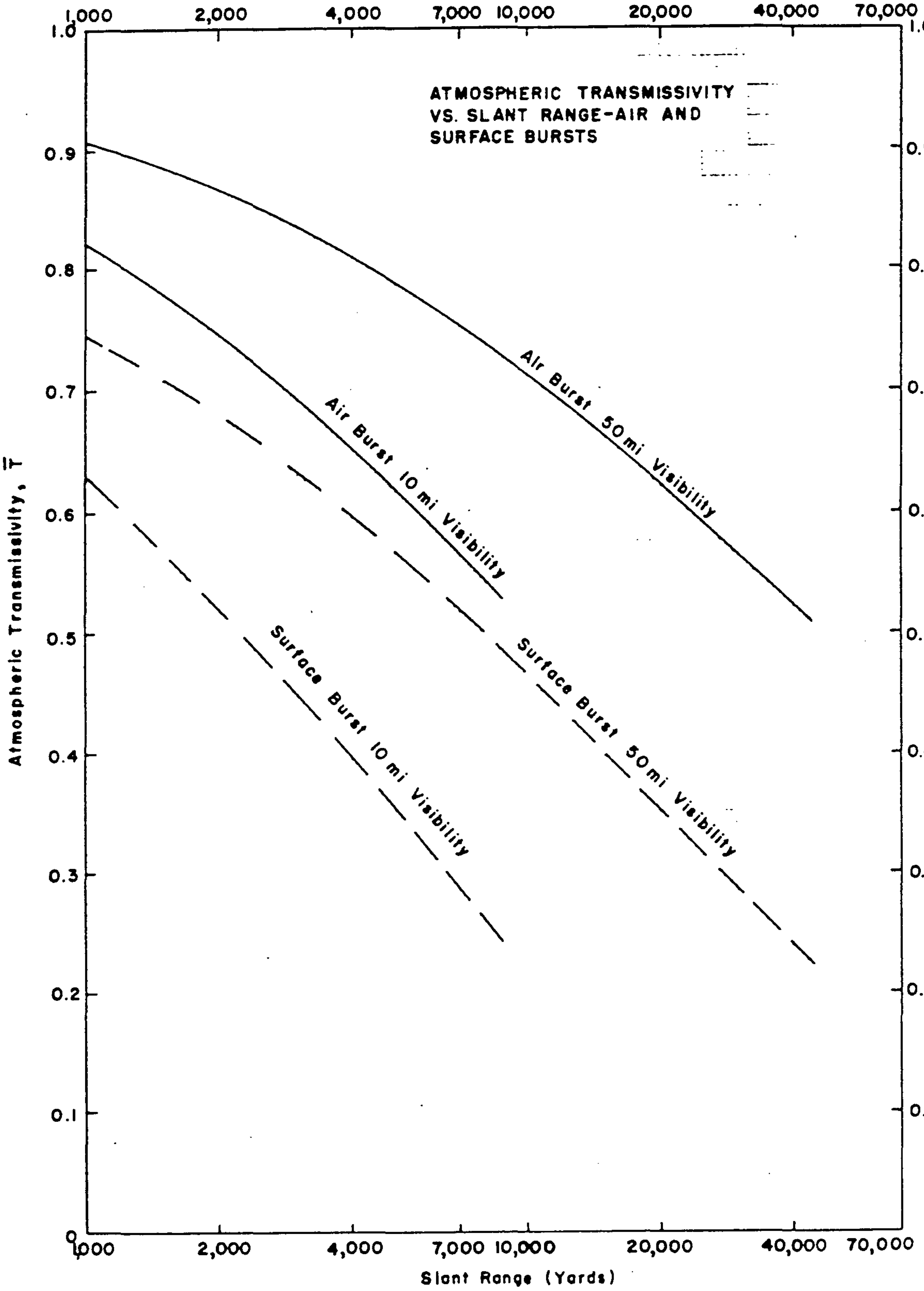
See also figures 3–6A and 3–6B.

FIGURE 3-5A



ATMOSPHERIC TRANSMISSIVITY
VS. SLANT RANGE-AIR AND
SURFACE BURSTS

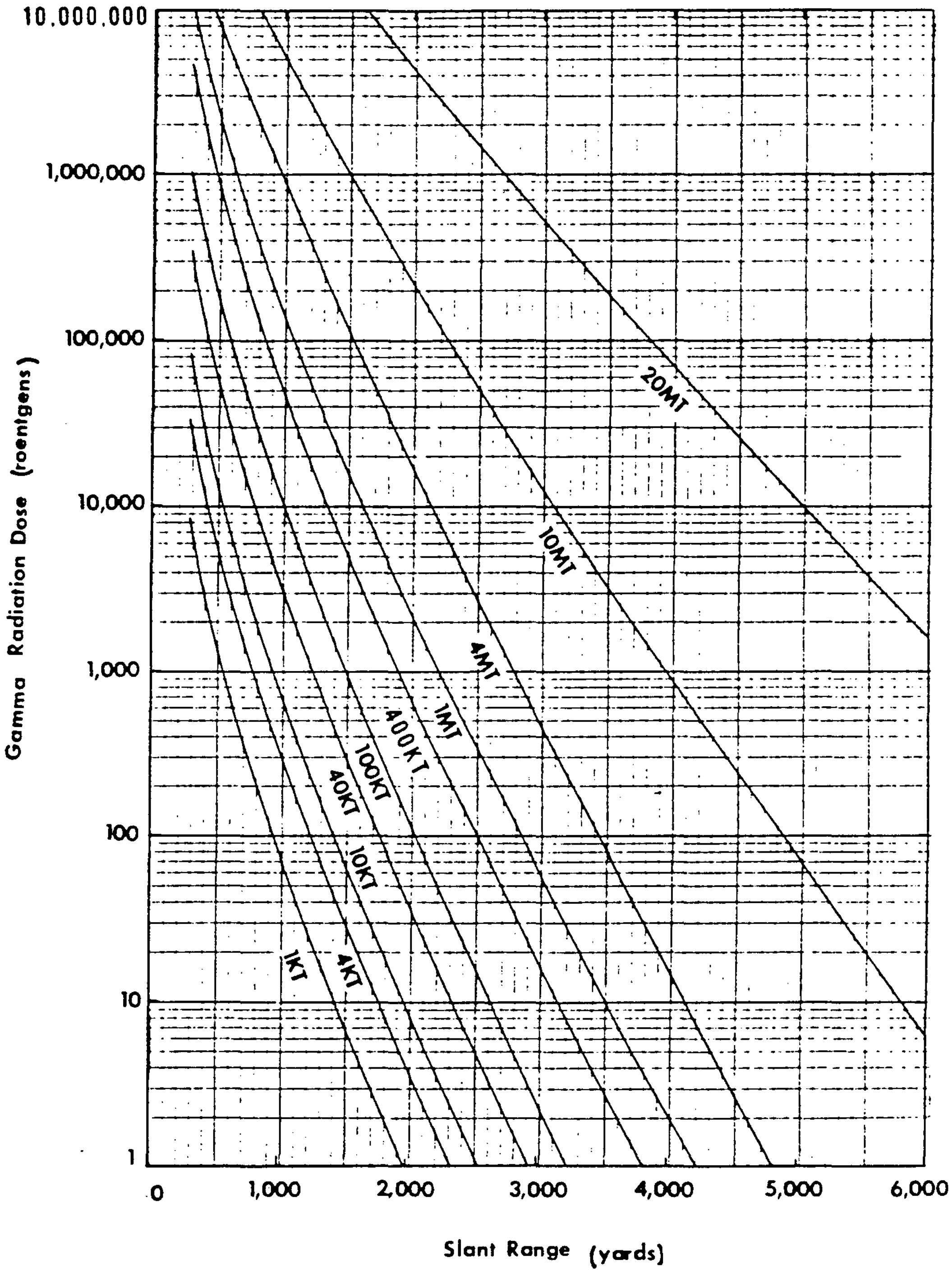
FIGURE 3–5B



ATMOSPHERIC TRANSMISSIVITY VS. SLANT RANGE-AIR AND SURFACE BURSTS

INITIAL GAMMA RADIATION DOSE VS SLANT RANGE
SURFACE BURST AND SURFACE TARGET

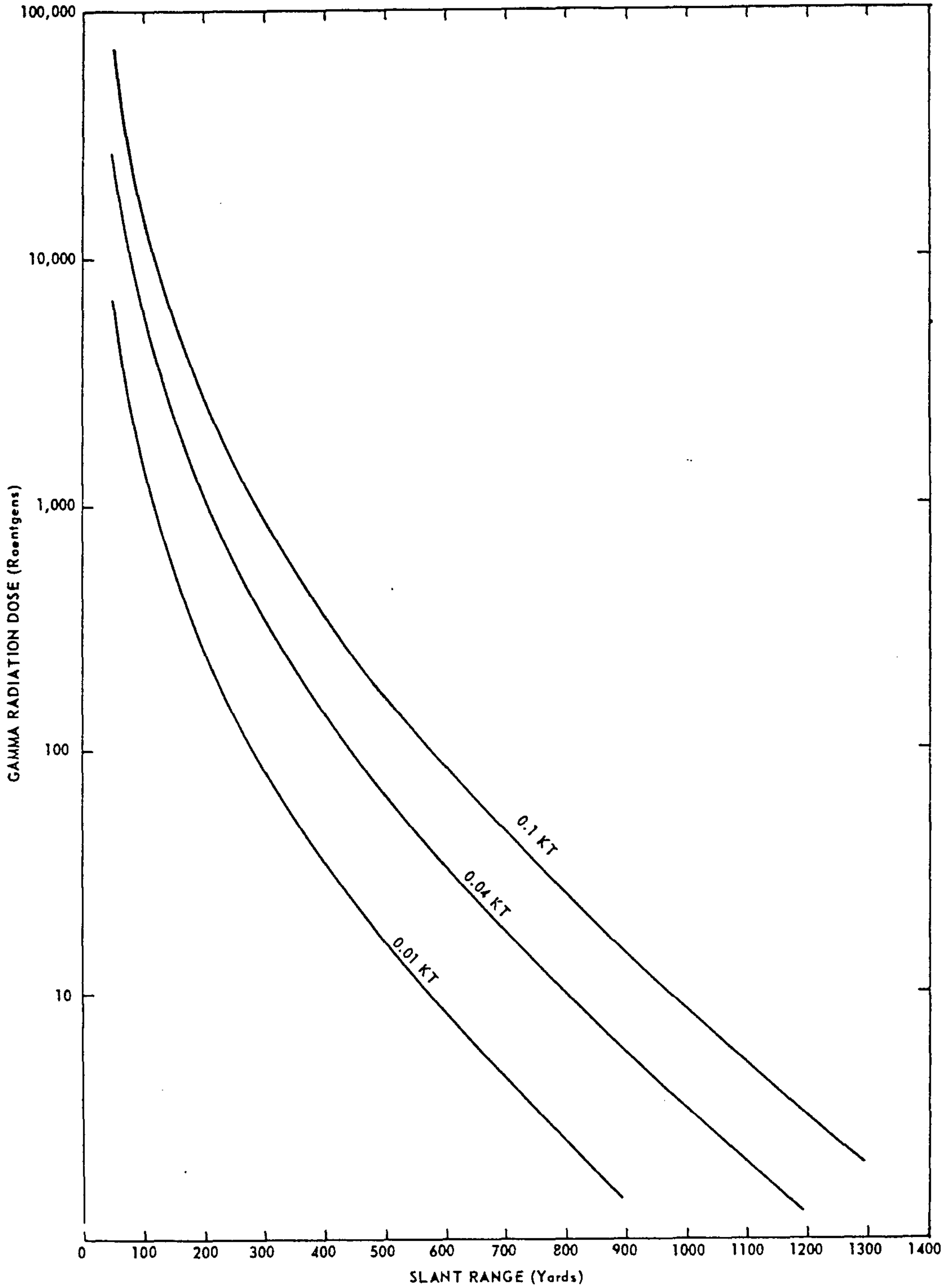
RELATIVE AIR DENSITY, 1.0



Note: Applicable to other situations as indicated on facing page.

FIGURE 4-7b

INITIAL GAMMA RADIATION DOSE vs SLANT RANGE
SURFACE BURST AND SURFACE TARGET
RELATIVE AIR DENSITY 1.0



NOTE: Applicable to other situations as indicated on facing page.

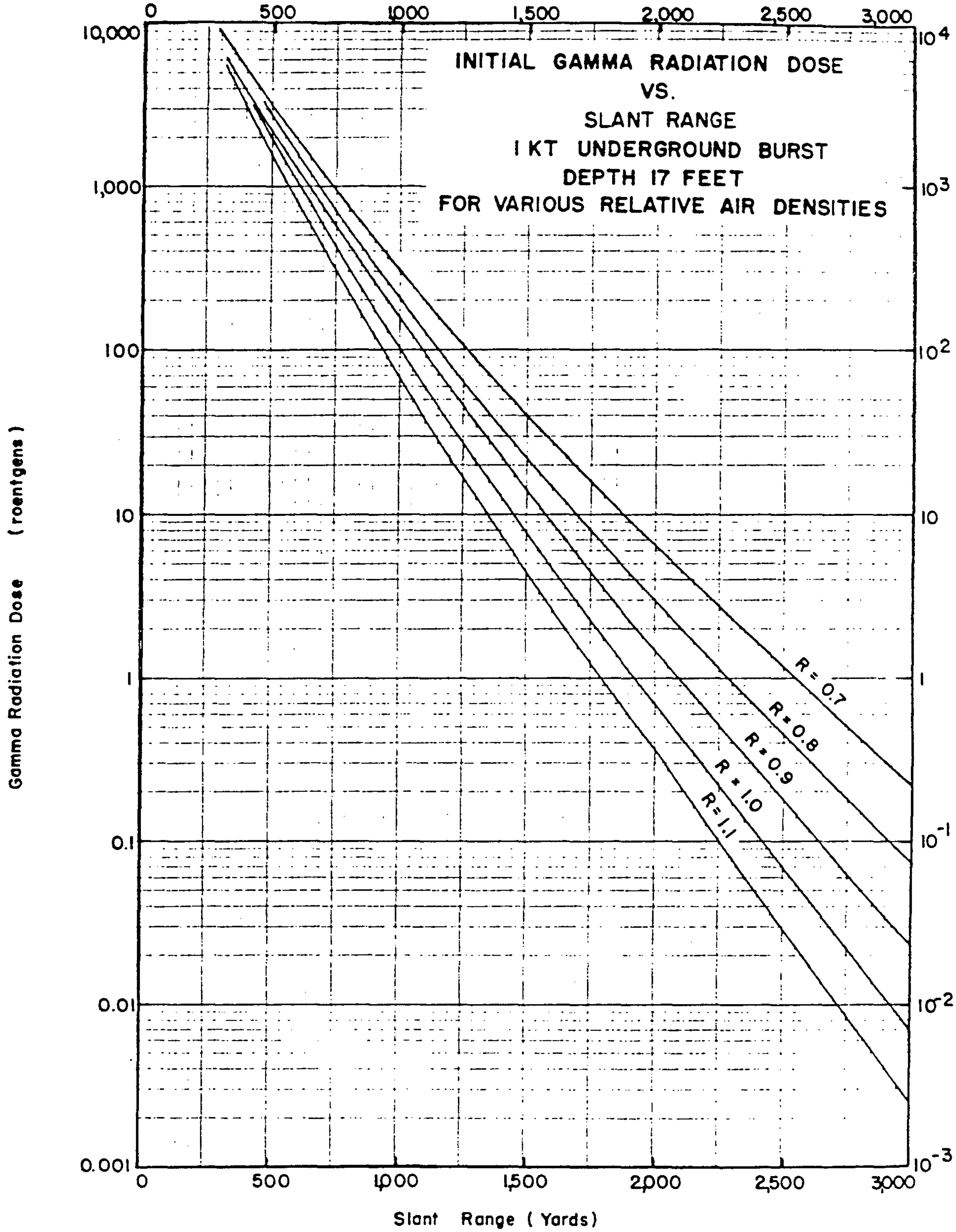
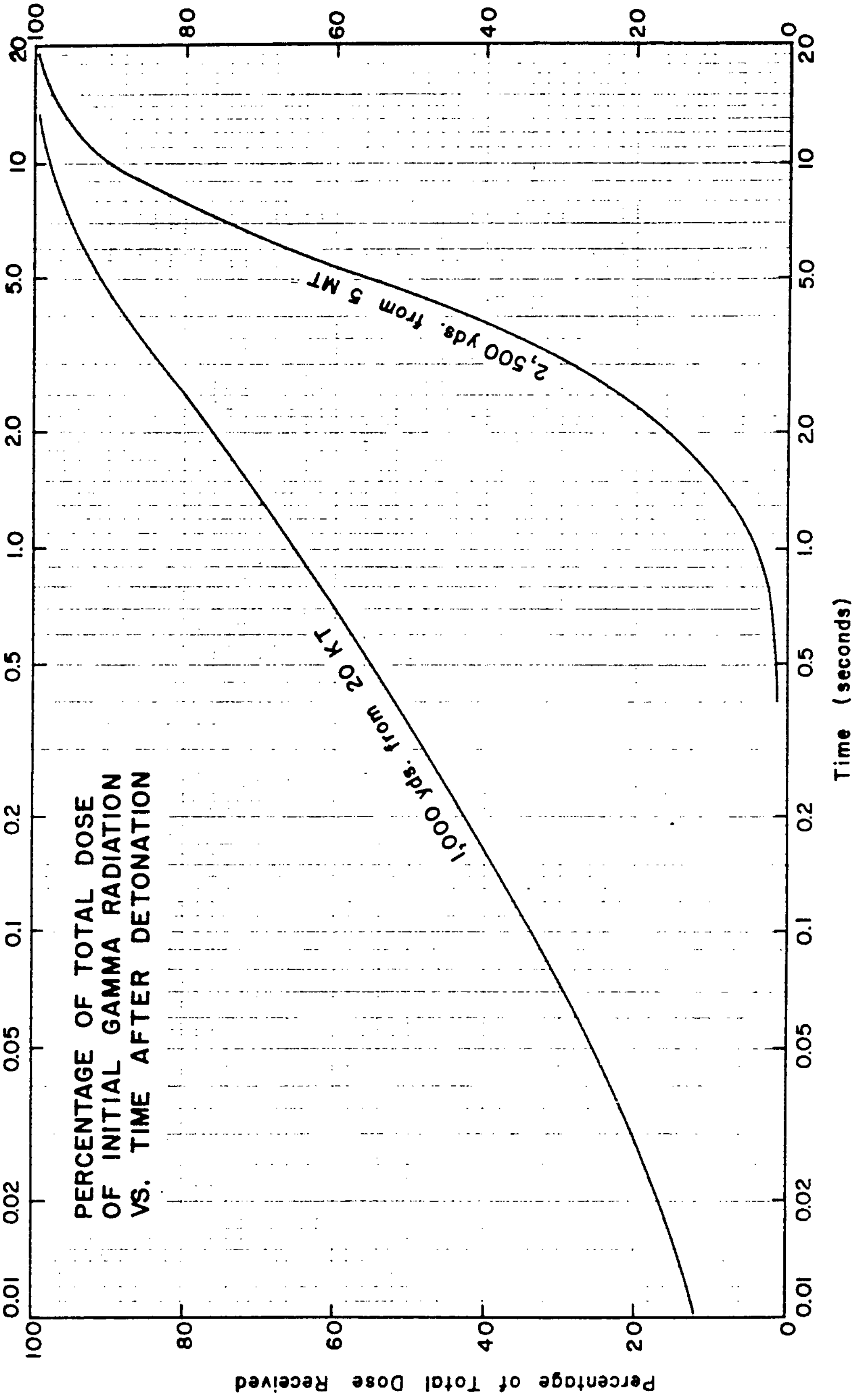
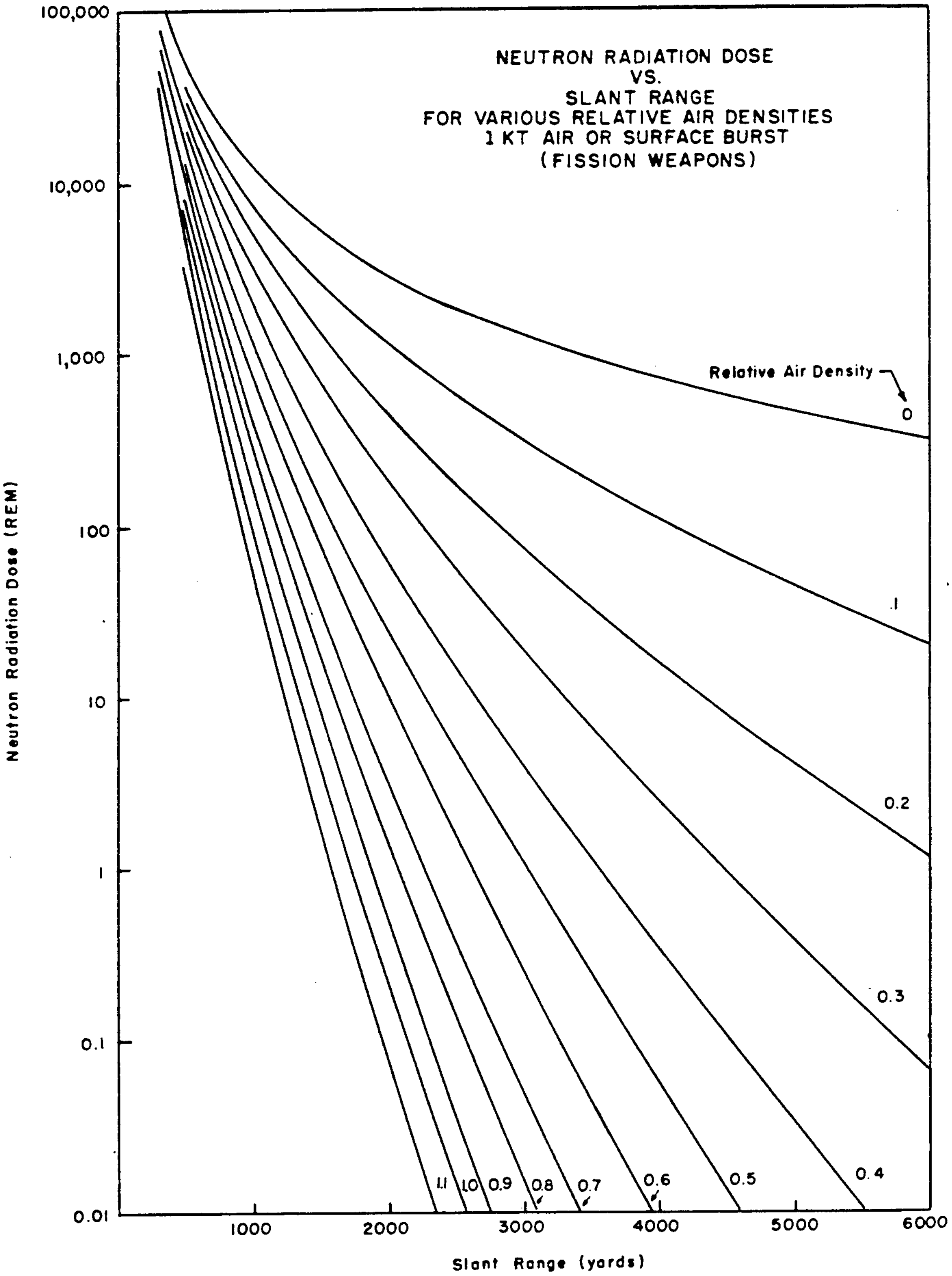
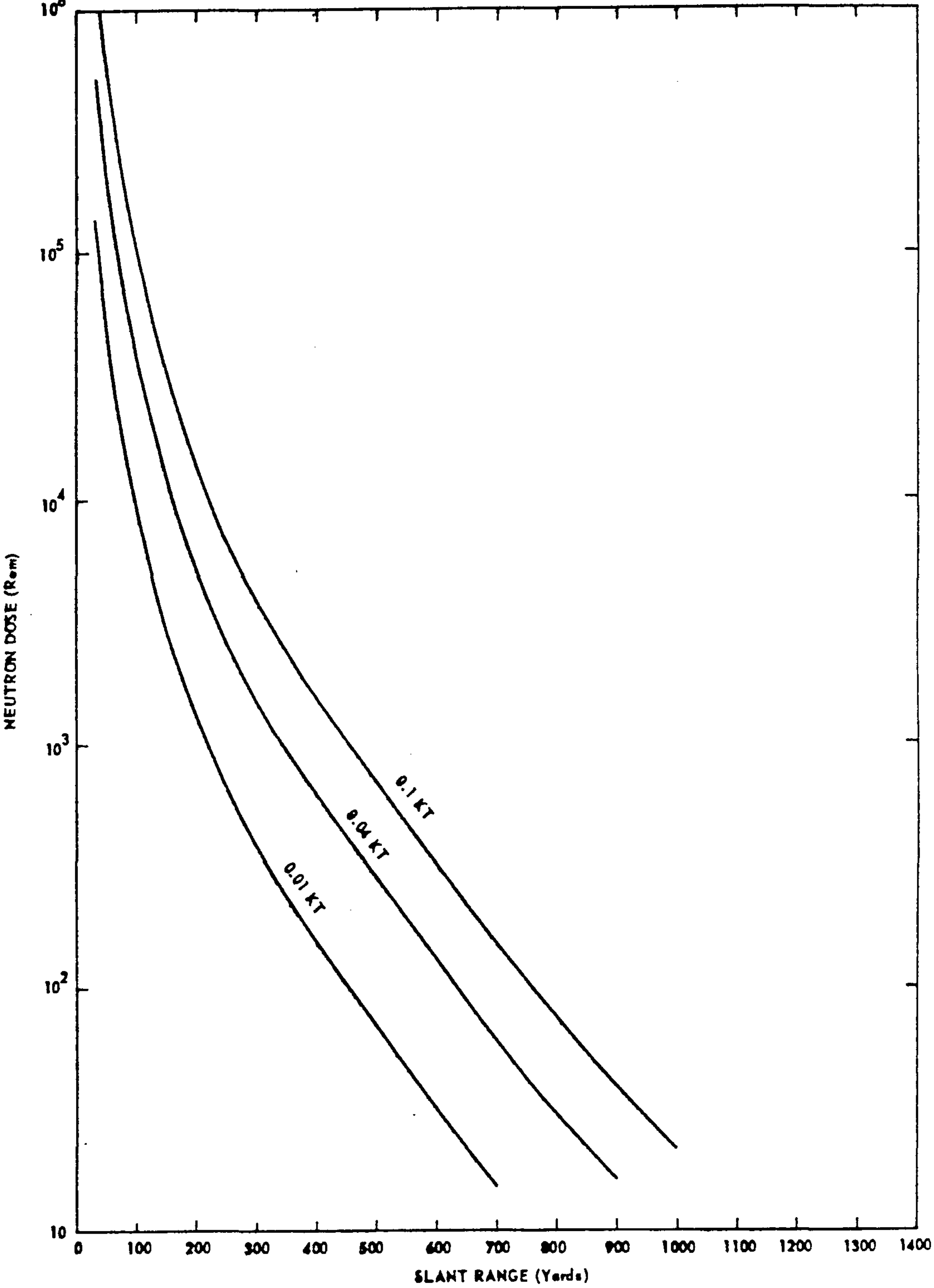

INITIAL GAMMA RADIATION DOSE
VS.
SLANT RANGE
1 KT UNDERGROUND BURST
DEPTH 17 FEET
FOR VARIOUS RELATIVE AIR DENSITIES
Gamma Radiation Dose (roentgens)
Slant Range (Yards)
10,000
1,000
100
10
1
0.1
0.01
0.001
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
0
500
1000
1,500
2,000
2,500
3,000
R = 0.7
R = 0.8
R = 0.9
R = 1.0
R = 1.1

FIGURE 4-9


PERCENTAGE OF TOTAL DOSE
OF INITIAL GAMMA RADIATION
VS. TIME AFTER DETONATION
2,500 yds. from 5 MT
1,000 yds. from 20 KT
Time (seconds)
Percentage of Total Dose Received
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2.0
5.0
10
20
100
80
60
40
20
0


NEUTRON RADIATION DOSE
VS.
SLANT RANGE
FOR VARIOUS RELATIVE AIR DENSITIES
1 KT AIR OR SURFACE BURST
(FISSION WEAPONS)
Relative Air Density
0
.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Neutron Radiation Dose (REM)
100,000
10,000
1,000
100
10
1
0.1
0.01
1000
2000
3000
4000
5000
6000
Slant Range (yards)

PROMPT NEUTRON DOSE vs SLANT RANGE
SURFACE BURST AND SURFACE TARGET
RELATIVE AIR DENSITY 1.0



NEUTRON RADIATION DOSE

(Fusion Weapons)

The curves presented in figure 4-11 may be regarded as representative of weapons in the megaton yield range.

Adjustment factors for receiver not on land surface	*Factor*
Water surface (or within 10 ft. thereof)	0. 9
Airborne, 300 ft. or more above land surface	1. 5

Scaling. At a given range and relative air density the neutron dose is proportional to the yield of the weapon. See appendix II for determination of relative air density.

Example.

Given: A 2 MT burst at an altitude of 2,000 feet above the surface where, at burst point, the pressure is 800 mb and, at the surface, the pressure is 860 mb.

Find: The slant range at which a minimum neutron dose of 500 rem would be received by a surface target.

Solution: From appendix II, the relative air density is 0.77.

The corresponding dose for 1 MT is—

$$\frac{500}{2}=250 \text{ rem.}$$

From figure 4-11 for $R=0.8$ and a dose of 250 rem, read slant range=3,400 yards. *Answer.*

Reliability. Very poor, due to almost complete lack of data and sensitivity of neutron flux to weapon design. Actual dose may be within a factor of 10 of dose computed using figure 4-11. Extrapolation of curves to slant ranges less than 2,000 yards is not recommended.

Related material.

See paragraph 4.2b.

See also figures 4-10 through 4-10d for fission weapons.

NEUTRON RADIATION DOSE VS. SLANT RANGE FOR VARIOUS RELATIVE AIR DENSITIES 1MT AIR OR SURFACE BURST (FUSION WEAPONS)

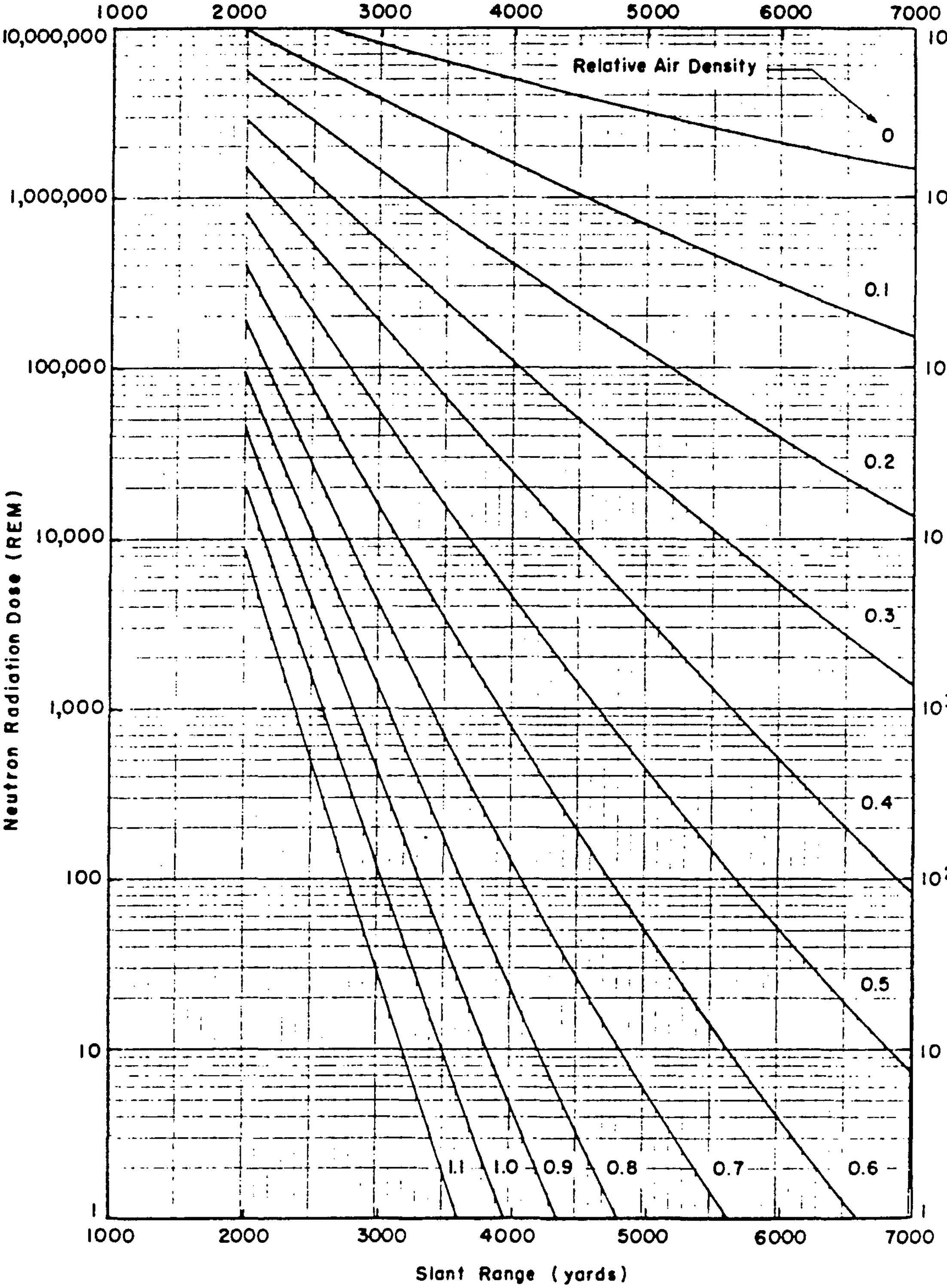
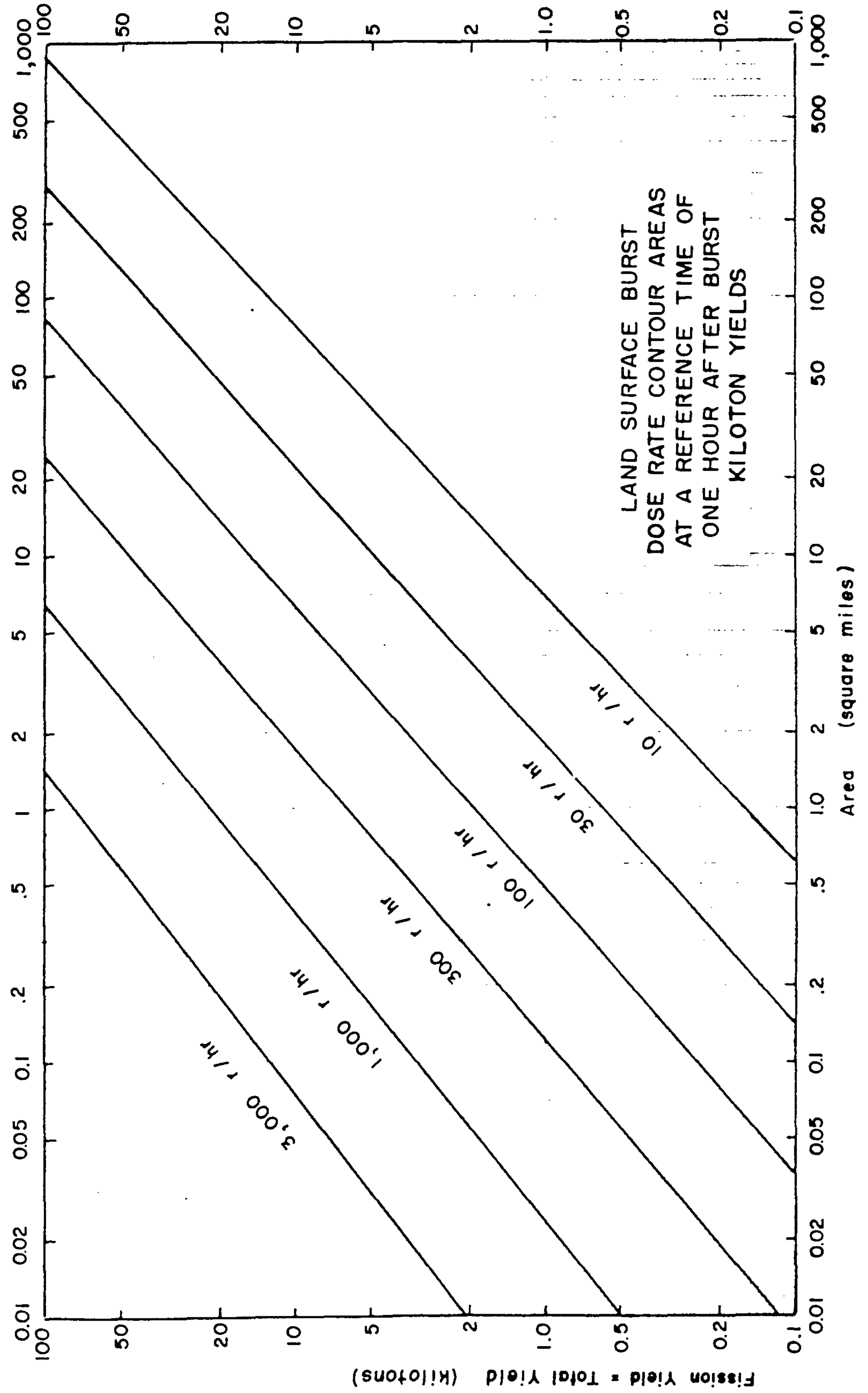
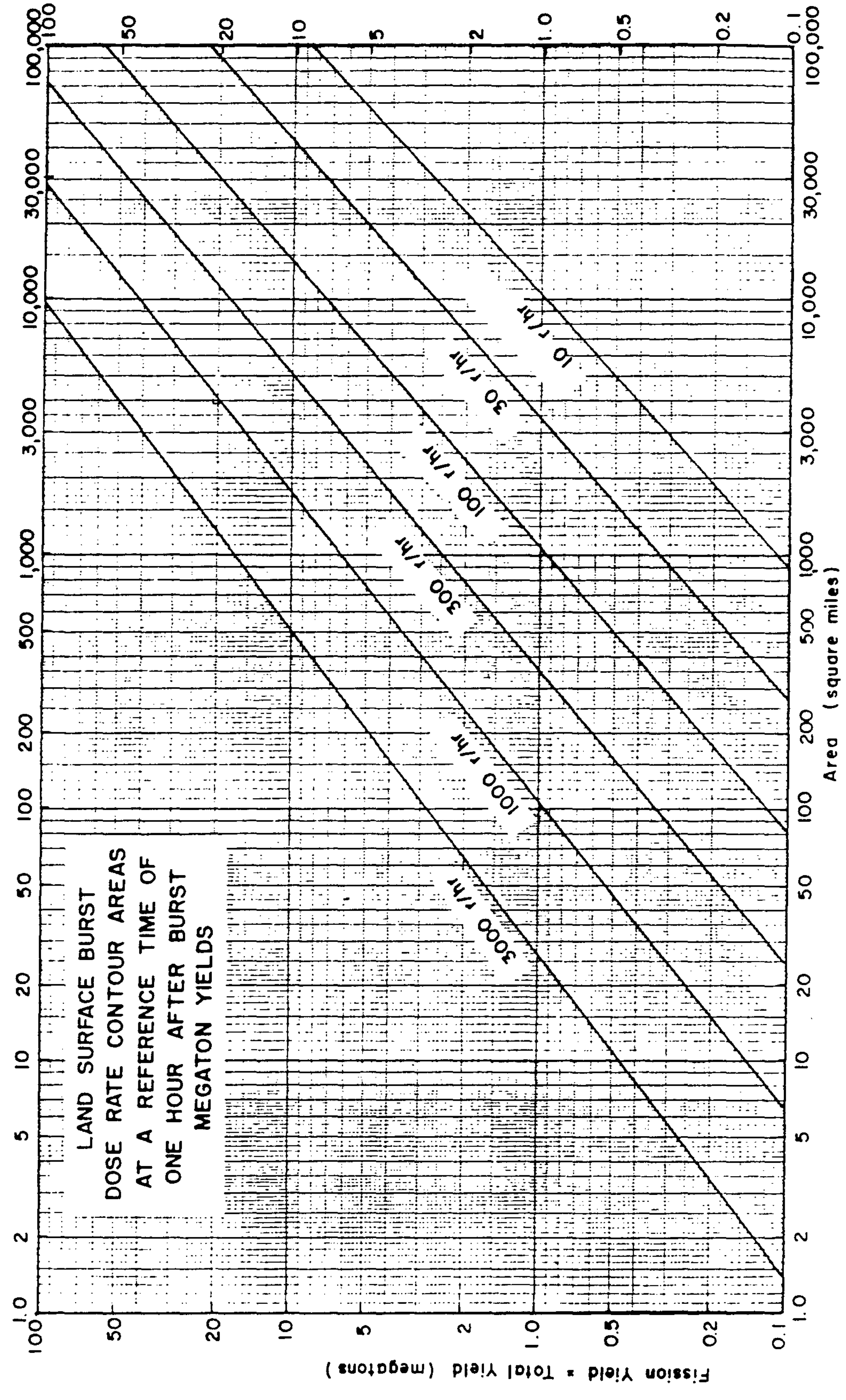


FIGURE 4-14A



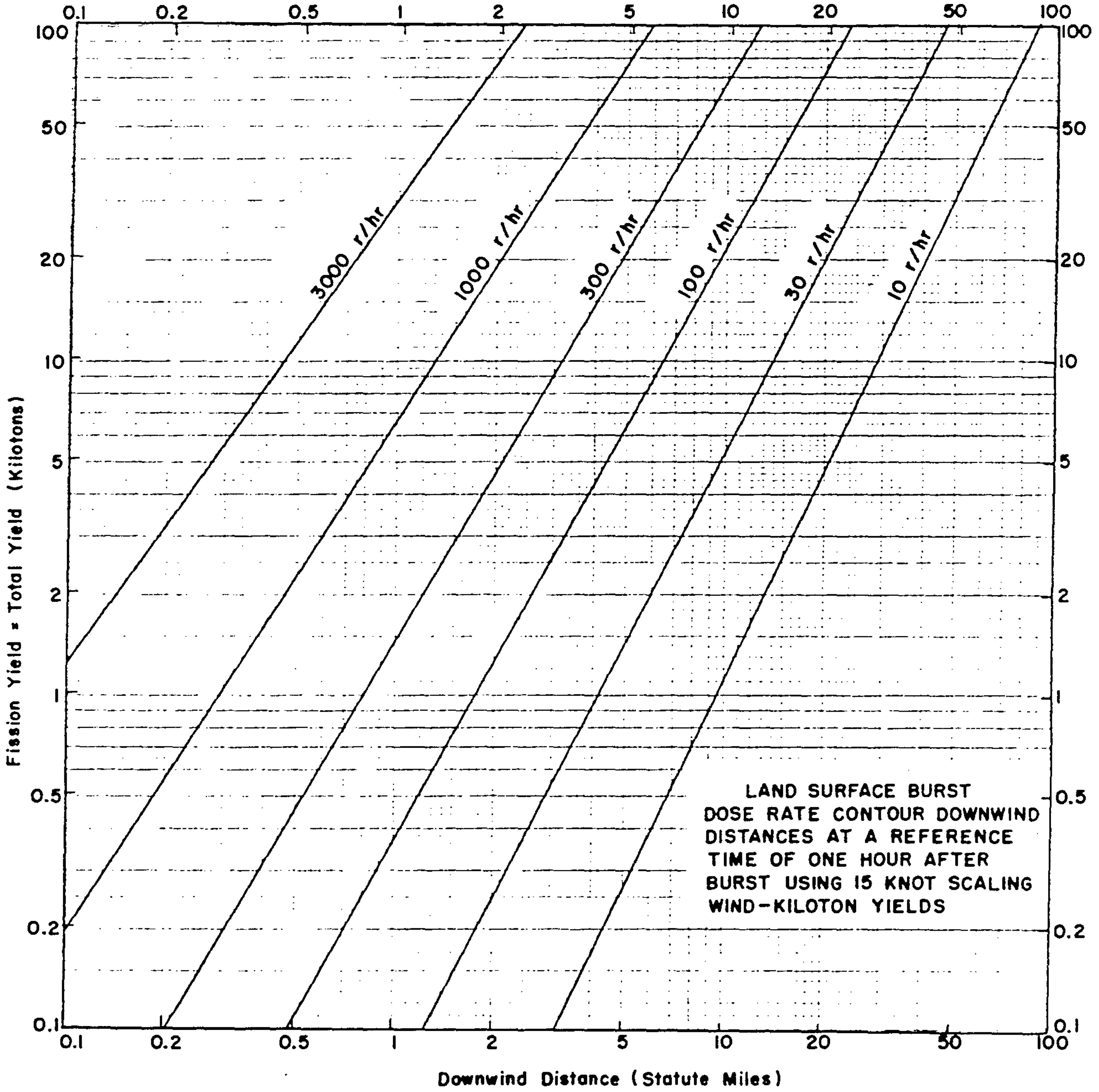
LAND SURFACE BURST
DOSE RATE CONTOUR AREAS
AT A REFERENCE TIME OF
ONE HOUR AFTER BURST
KILOTON YIELDS

FIGURE 4-14B



LAND SURFACE BURST
DOSE RATE CONTOUR AREAS
AT A REFERENCE TIME OF
ONE HOUR AFTER BURST
MEGATON YIELDS

FIGURE 4-15A



LAND SURFACE BURST
DOSE RATE CONTOUR DOWNWIND
DISTANCES AT A REFERENCE
TIME OF ONE HOUR AFTER
BURST USING 15 KNOT SCALING
WIND-KILOTON YIELDS

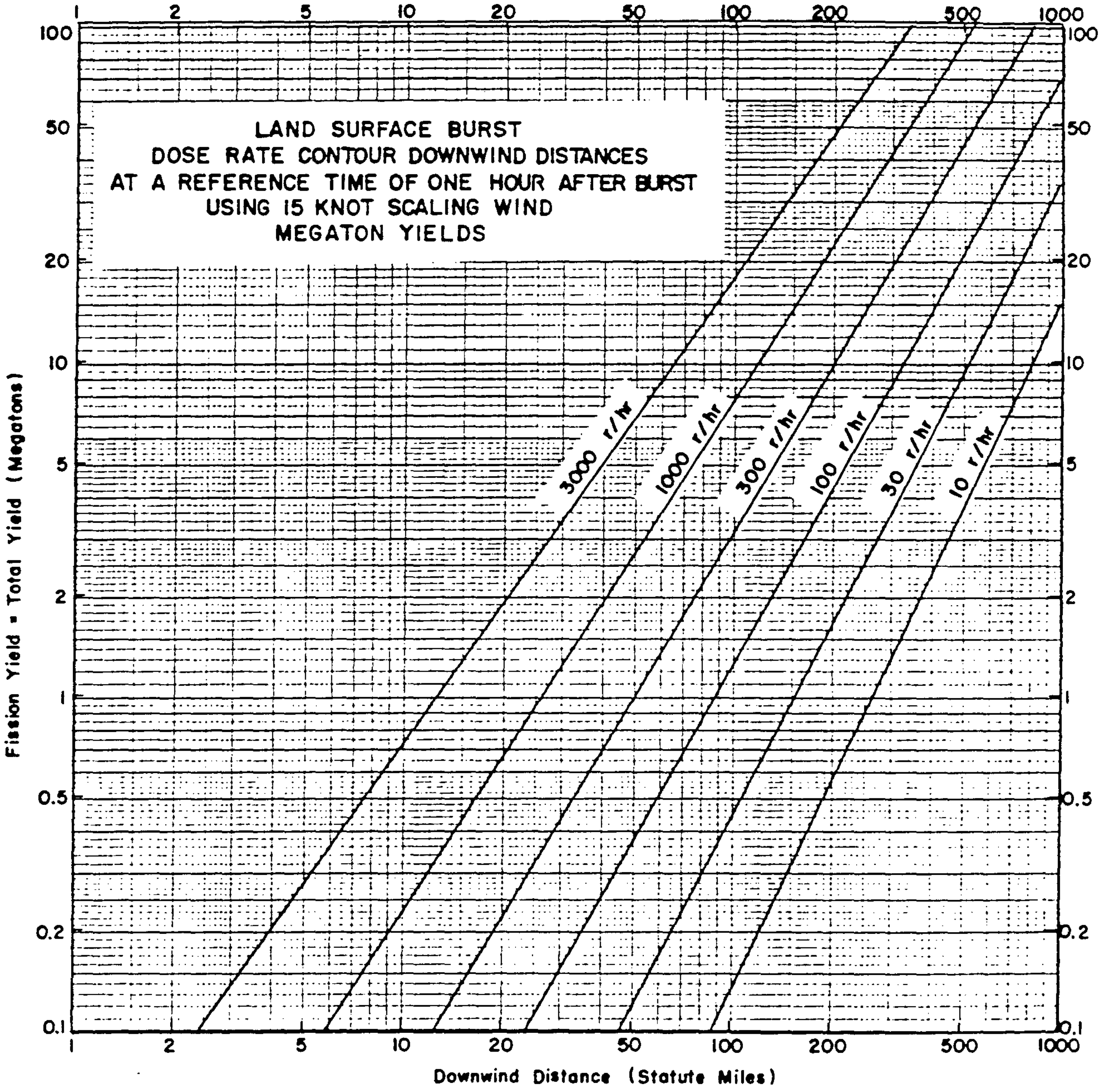
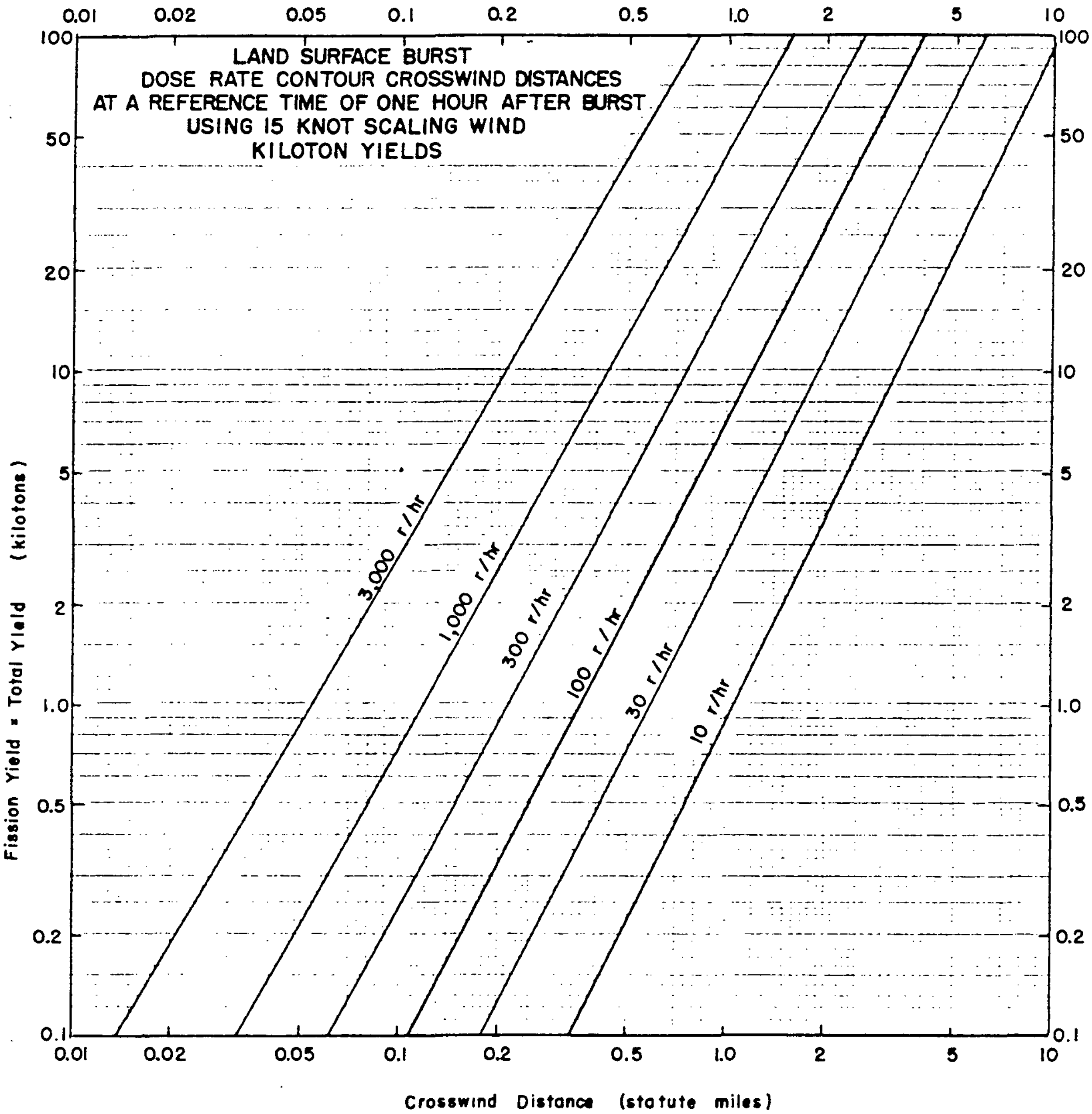
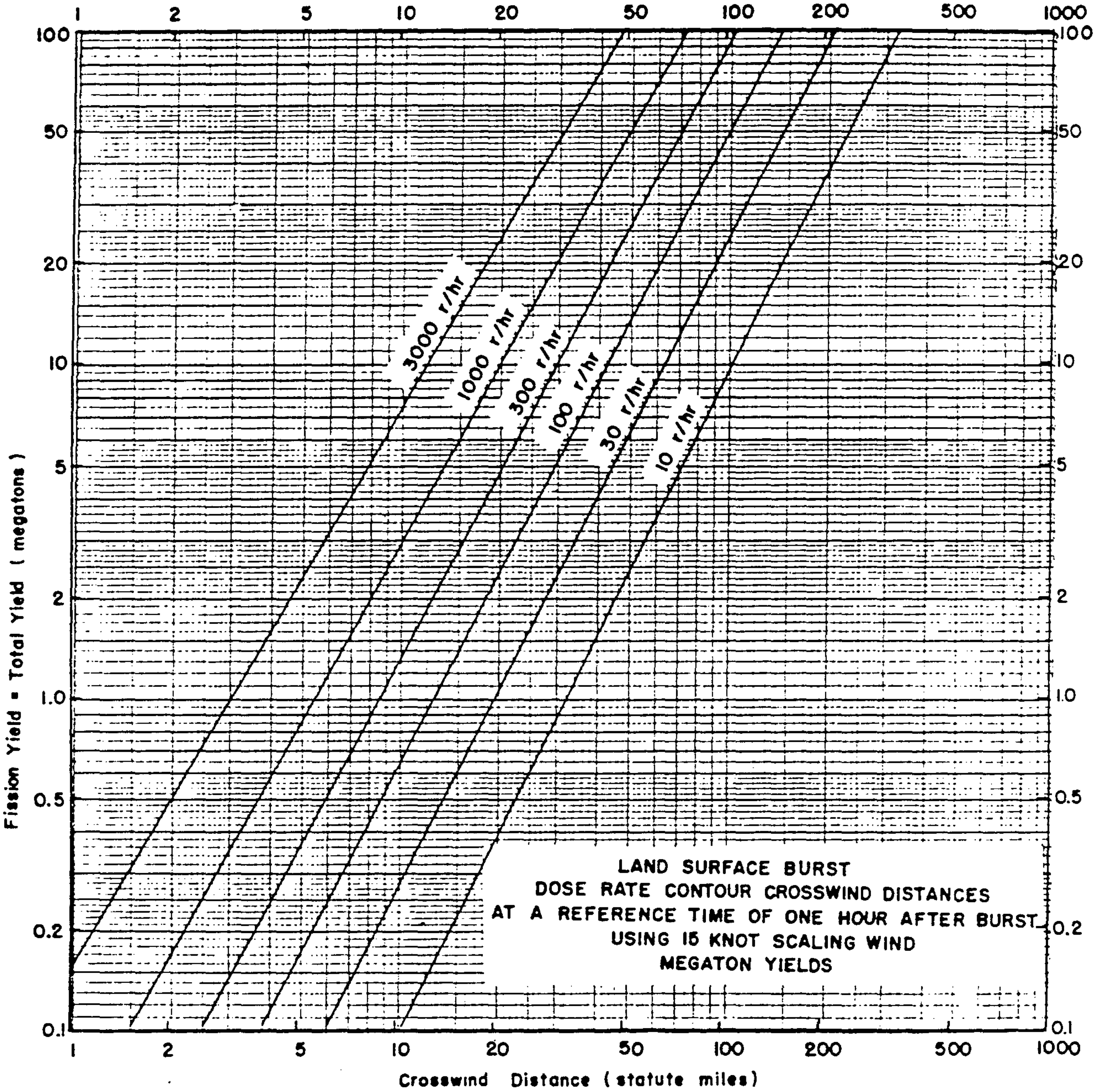

LAND SURFACE BURST
DOSE RATE CONTOUR DOWNWIND DISTANCES
AT A REFERENCE TIME OF ONE HOUR AFTER BURST
USING 15 KNOT SCALING WIND
MEGATON YIELDS
3000 r/hr
1000 r/hr
300 r/hr
100 r/hr
30 r/hr
10 r/hr
Fission Yield = Total Yield (Megatons)
0.1
0.2
0.5
1
2
5
10
20
50
100
Downwind Distance (Statute Miles)
1
2
5
10
20
50
100
200
500
1000

FIGURE 4-16A


LAND SURFACE BURST
DOSE RATE CONTOUR CROSSWIND DISTANCES
AT A REFERENCE TIME OF ONE HOUR AFTER BURST
USING 15 KNOT SCALING WIND
KILOTON YIELDS
3,000 r/hr
1,000 r/hr
300 r/hr
100 r/hr
30 r/hr
10 r/hr
Fission Yield × Total Yield (kilotons)
Crosswind Distance (statute miles)
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2
5
10
0.1
0.2
0.5
1.0
2
5
10
20
50
100



LAND SURFACE BURST
DOSE RATE CONTOUR CROSSWIND DISTANCES
AT A REFERENCE TIME OF ONE HOUR AFTER BURST
USING 15 KNOT SCALING WIND
MEGATON YIELDS

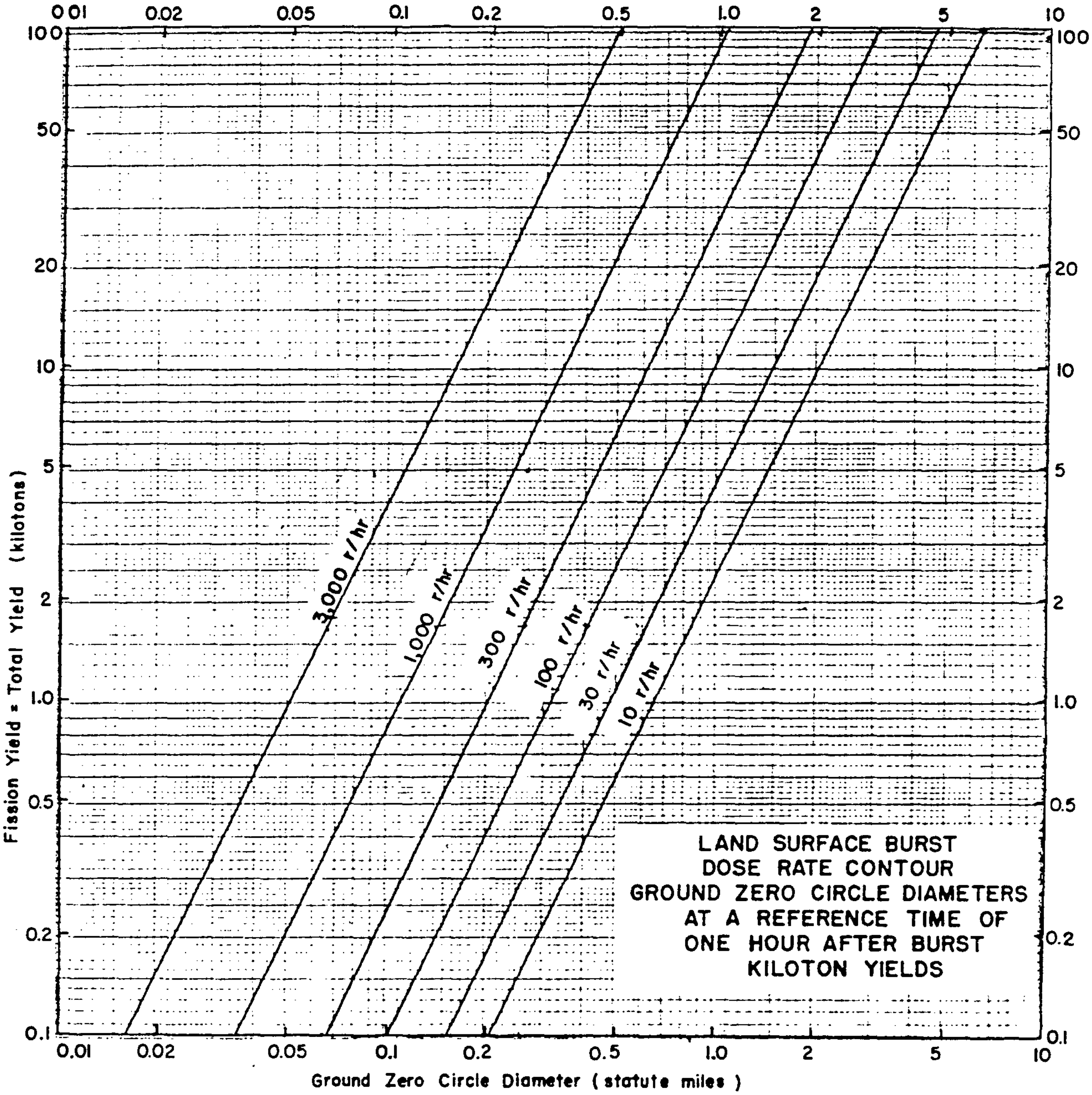

LAND SURFACE BURST
DOSE RATE CONTOUR
GROUND ZERO CIRCLE DIAMETERS
AT A REFERENCE TIME OF
ONE HOUR AFTER BURST
KILOTON YIELDS
3,000 r/hr
1,000 r/hr
300 r/hr
100 r/hr
30 r/hr
10 r/hr
Fission Yield = Total Yield (kilotons)
Ground Zero Circle Diameter (statute miles)
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2
5
10
100
50
20
10
5
2
1.0
0.5
0.2
0.1

FIGURE 4-17B

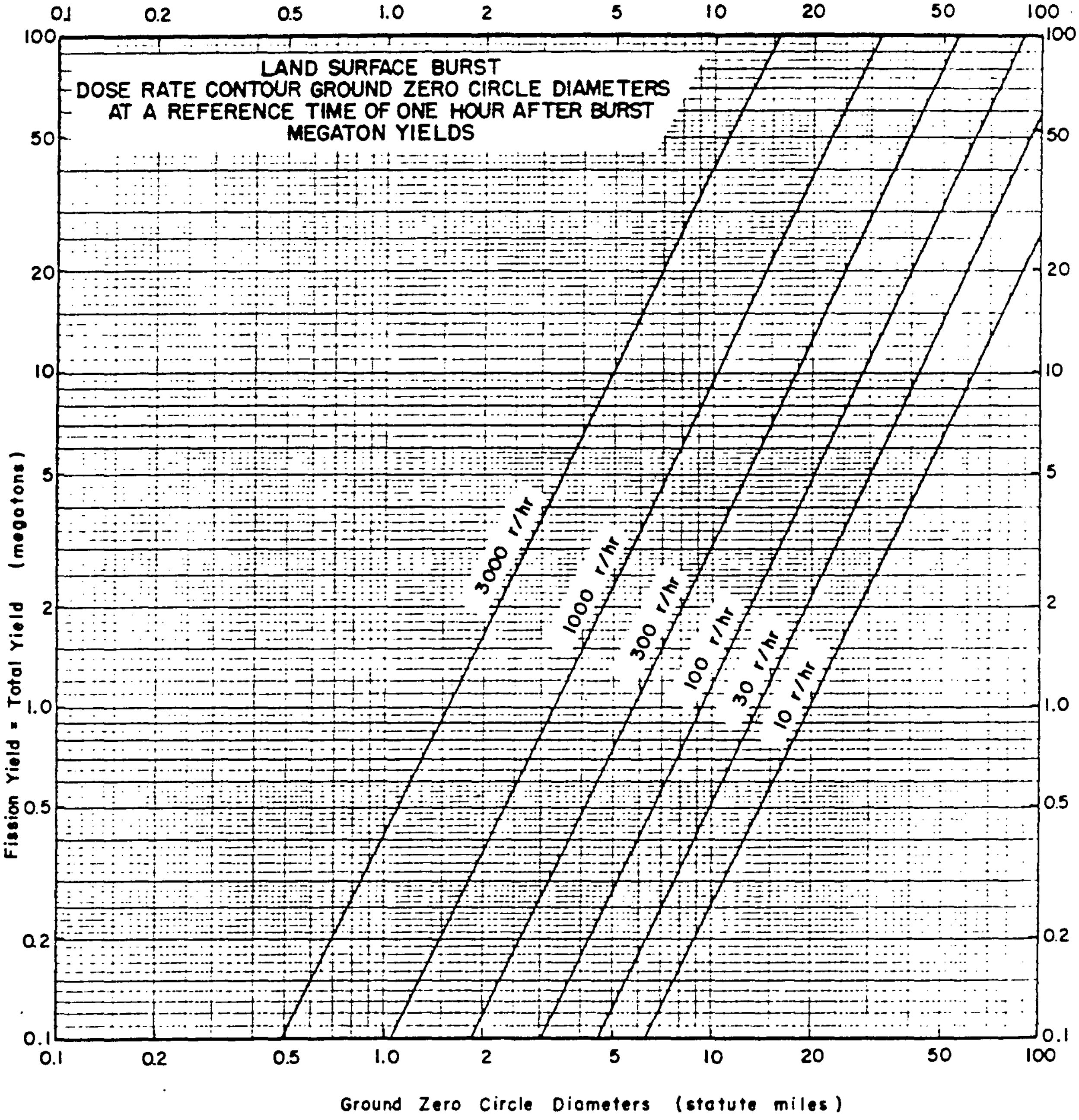
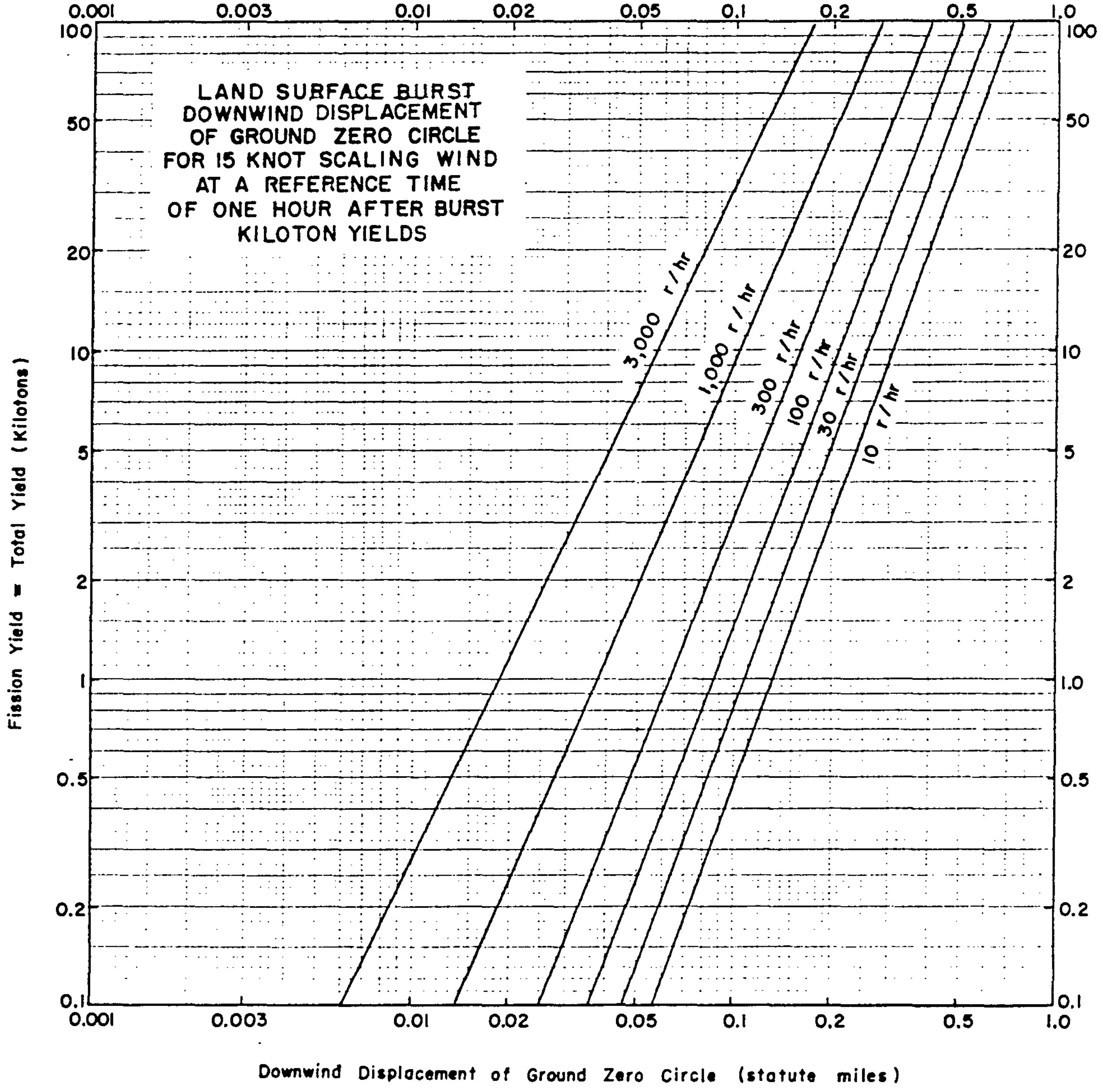

LAND SURFACE BURST
DOSE RATE CONTOUR GROUND ZERO CIRCLE DIAMETERS
AT A REFERENCE TIME OF ONE HOUR AFTER BURST
MEGATON YIELDS
3000 r/hr
1000 r/hr
300 r/hr
100 r/hr
30 r/hr
10 r/hr
0.1
0.2
0.5
1.0
2
5
10
20
50
100
Fission Yield = Total Yield (megatons)
Ground Zero Circle Diameters (statute miles)

FIGURE 4-18A



LAND SURFACE BURST
DOWNWIND DISPLACEMENT
OF GROUND ZERO CIRCLE
FOR 15 KNOT SCALING WIND
AT A REFERENCE TIME
OF ONE HOUR AFTER BURST
KILOTON YIELDS

FIGURE 4-18B

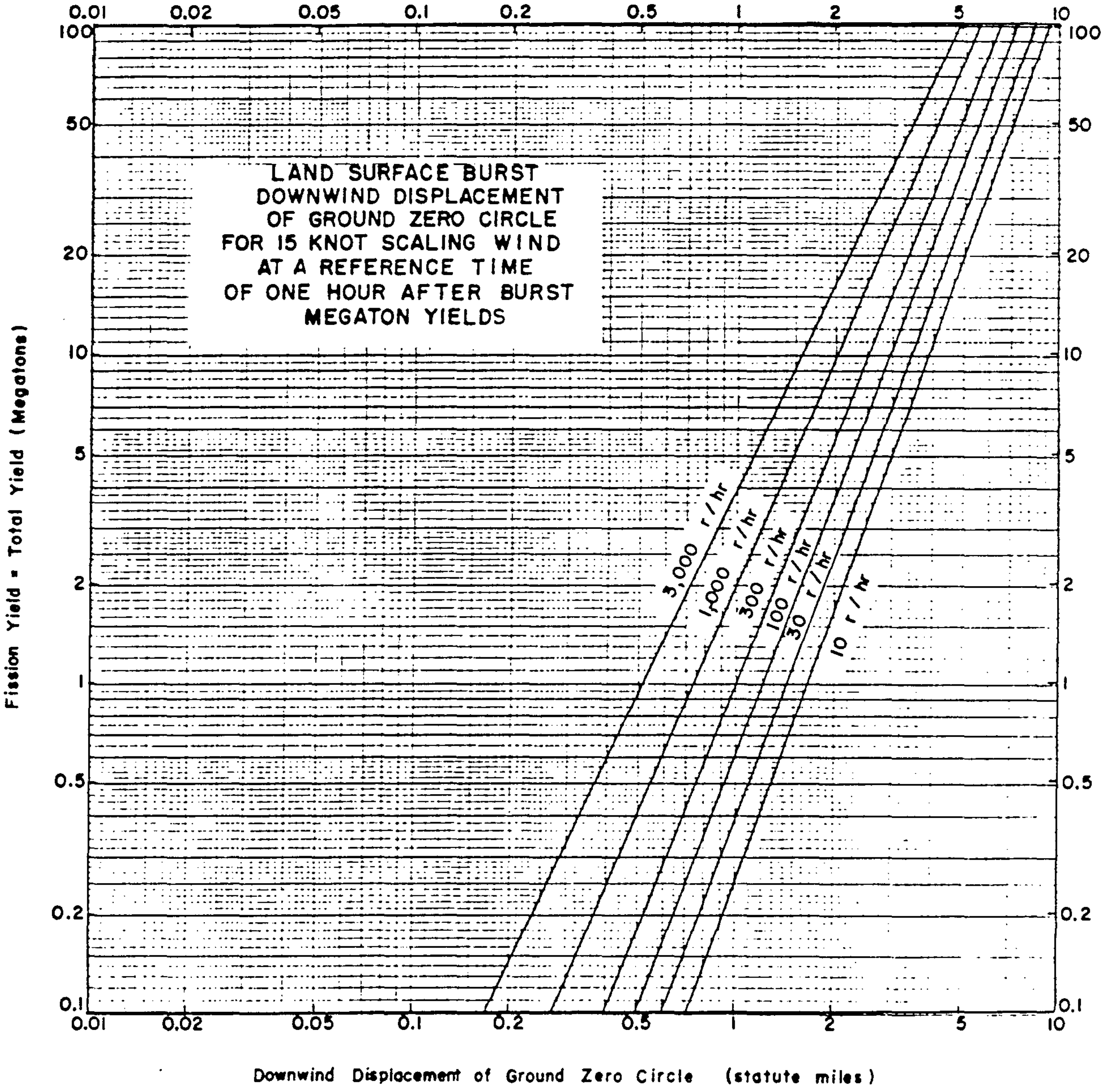
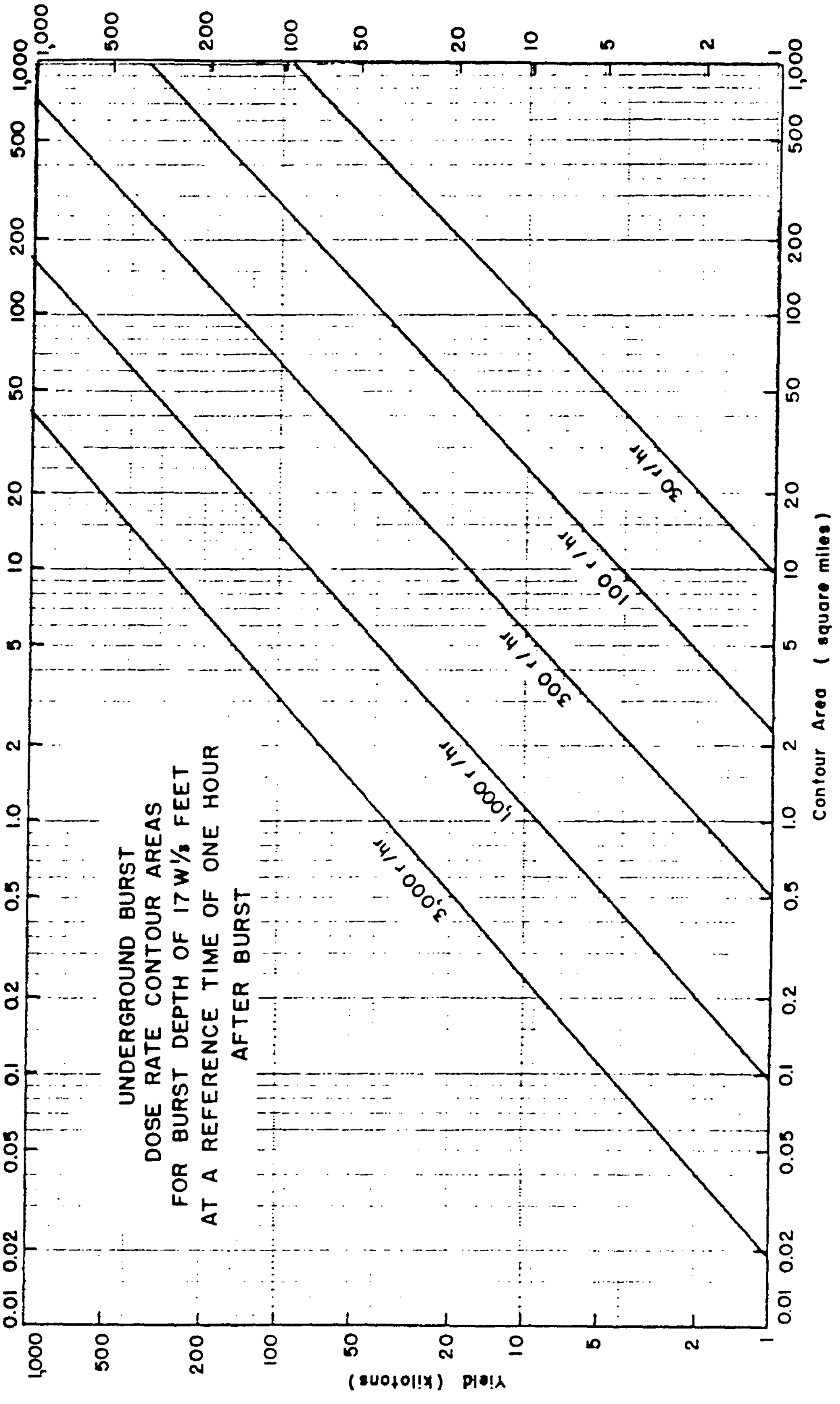

LAND SURFACE BURST
DOWNWIND DISPLACEMENT
OF GROUND ZERO CIRCLE
FOR 15 KNOT SCALING WIND
AT A REFERENCE TIME
OF ONE HOUR AFTER BURST
MEGATON YIELDS
3,000 r/hr
1,000 r/hr
300 r/hr
100 r/hr
30 r/hr
10 r/hr
Fission Yield = Total Yield (Megatons)
100
50
20
10
5
2
1
0.5
0.2
0.1
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
Downwind Displacement of Ground Zero Circle (statute miles)

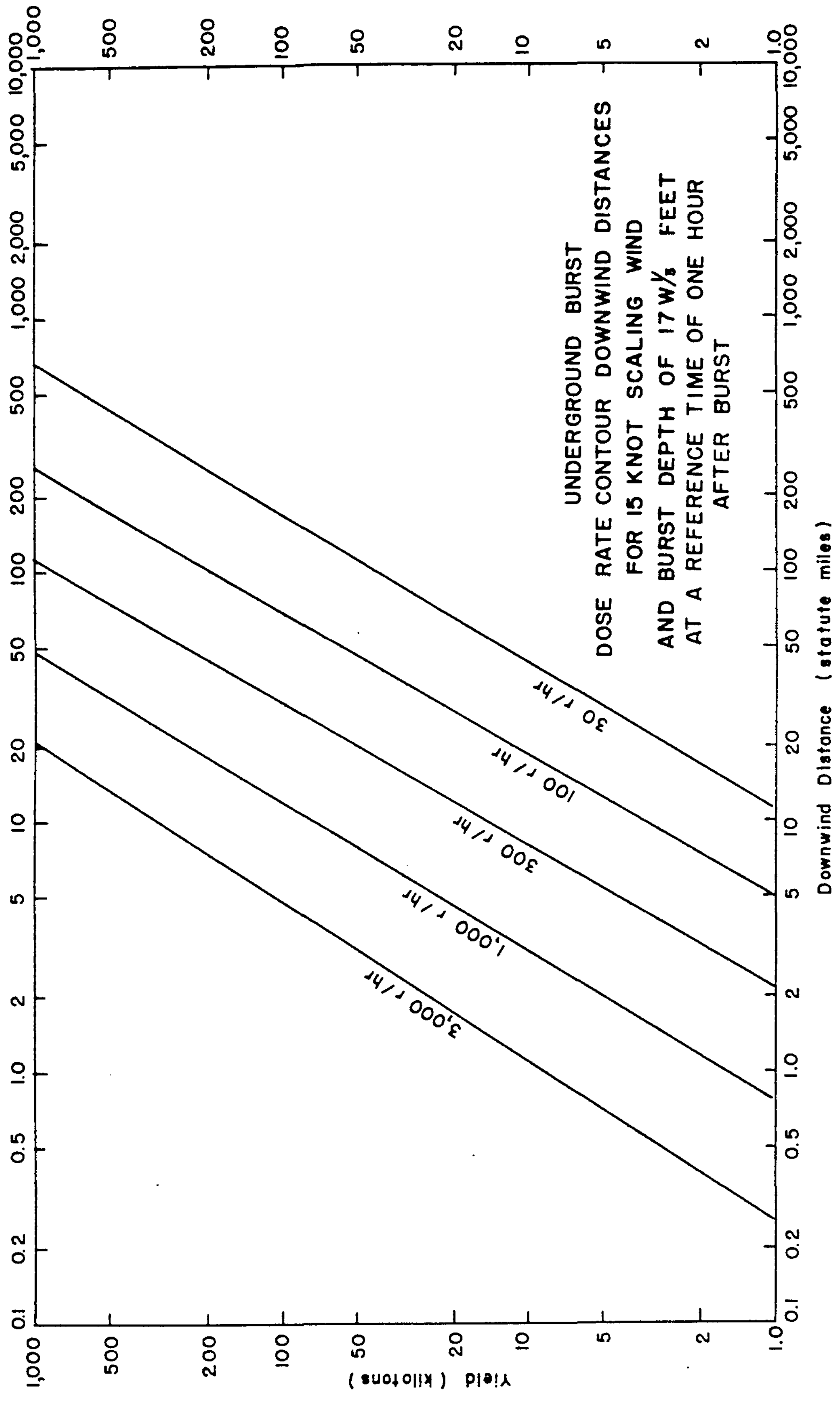
FIGURE 4-20



UNDERGROUND BURST
DOSE RATE CONTOUR AREAS
FOR BURST DEPTH OF 17 W$^{1/3}$ FEET
AT A REFERENCE TIME OF ONE HOUR
AFTER BURST

FIGURE 4-21

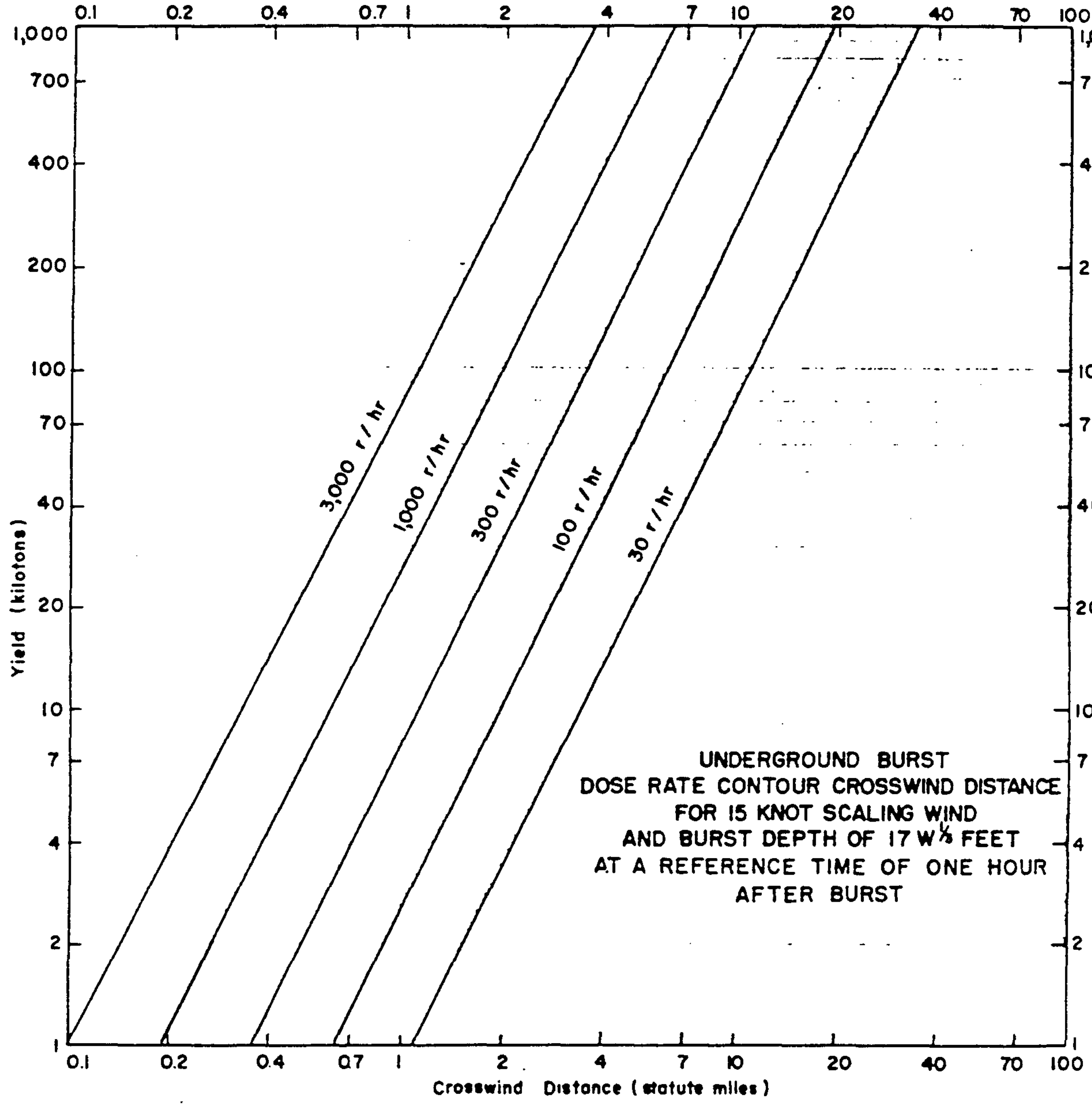
~~CONFIDENTIAL~~



UNDERGROUND BURST
DOSE RATE CONTOUR DOWNWIND DISTANCES
FOR 15 KNOT SCALING WIND
AND BURST DEPTH OF 17 W$^{1/3}$ FEET
AT A REFERENCE TIME OF ONE HOUR
AFTER BURST

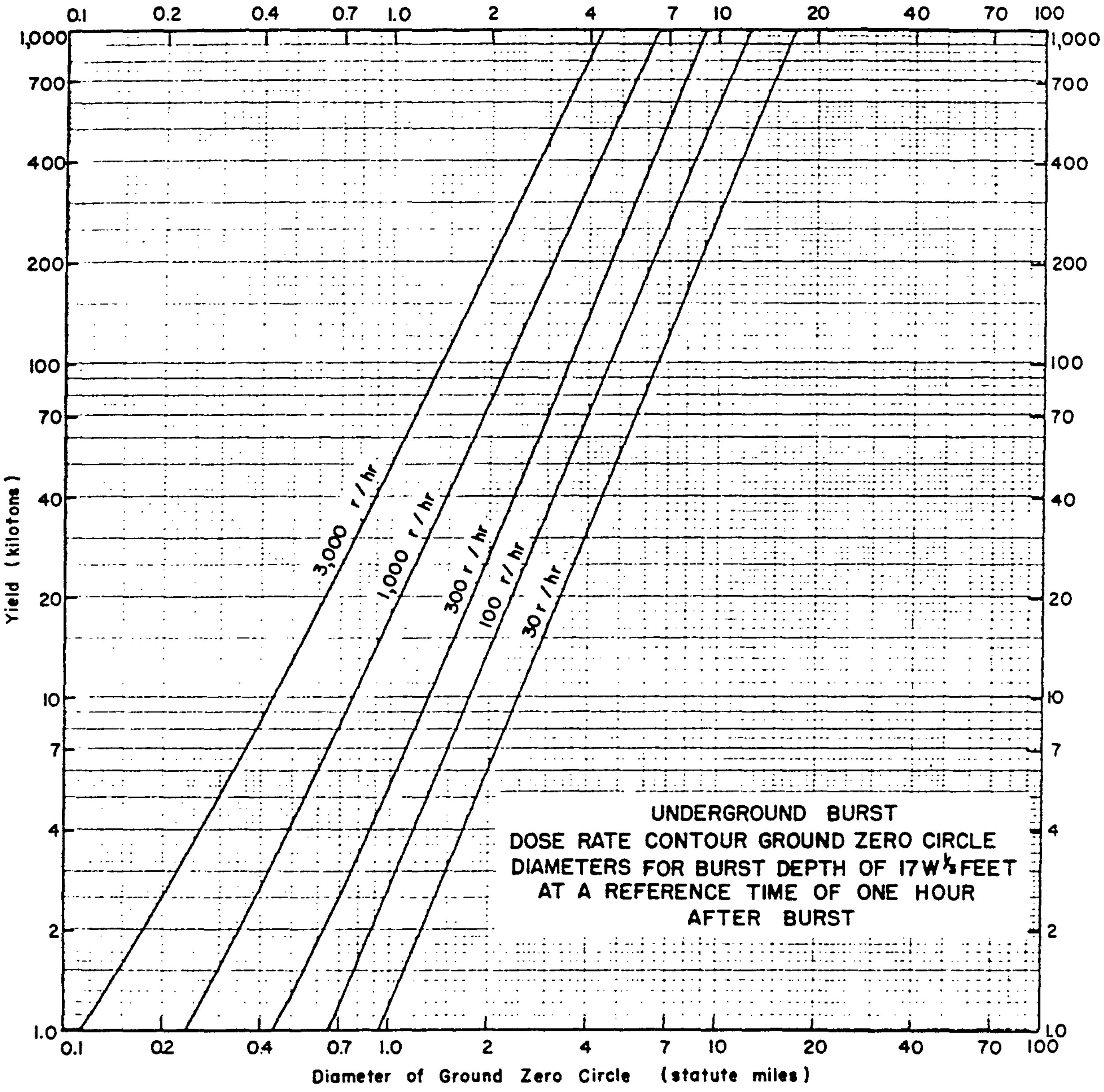
~~CONFIDENTIAL~~

FIGURE 4-22



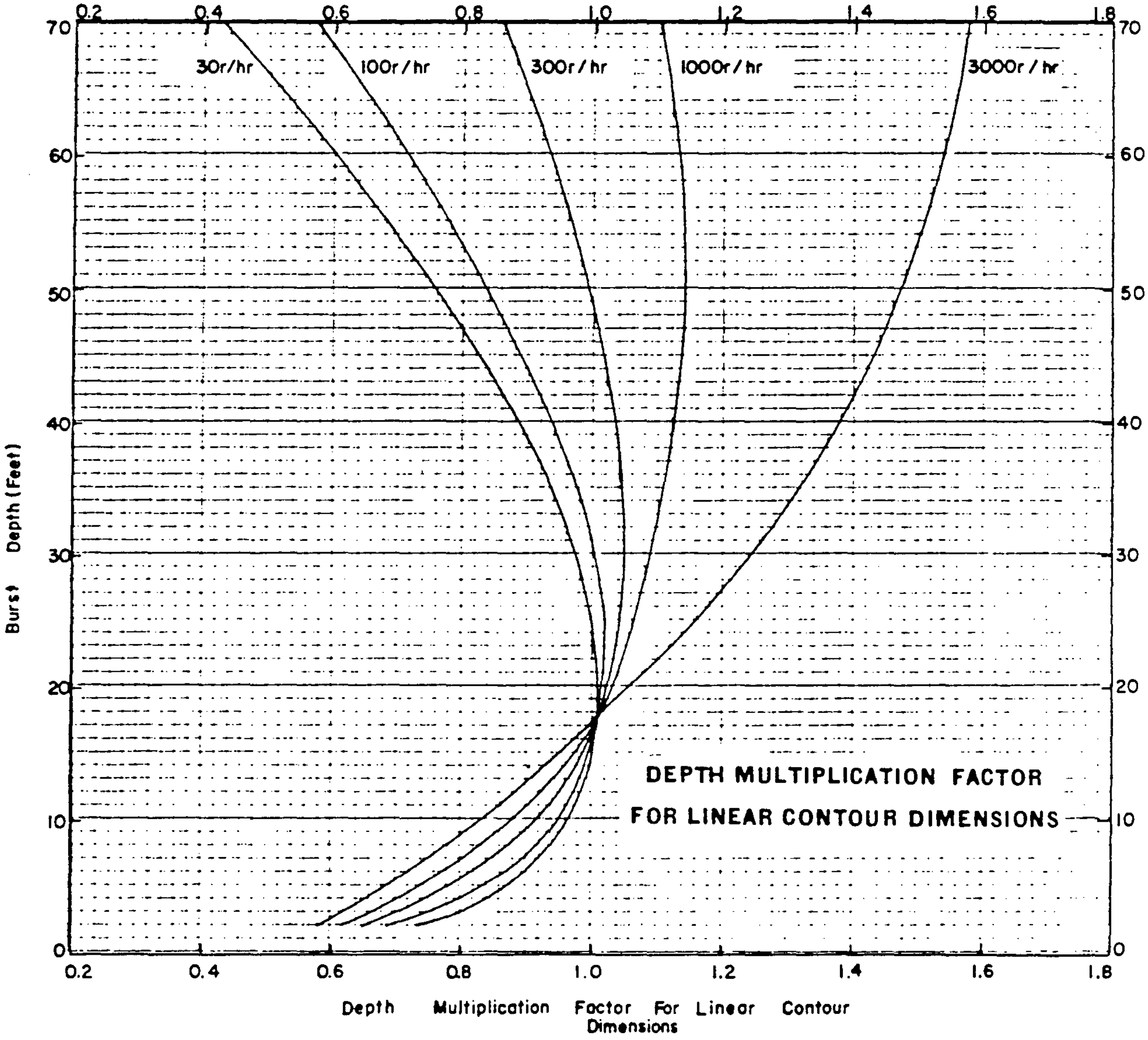
UNDERGROUND BURST
DOSE RATE CONTOUR CROSSWIND DISTANCE
FOR 15 KNOT SCALING WIND
AND BURST DEPTH OF 17 $W^{1/3}$ FEET
AT A REFERENCE TIME OF ONE HOUR
AFTER BURST

FIGURE 4-23



UNDERGROUND BURST
DOSE RATE CONTOUR GROUND ZERO CIRCLE DIAMETERS FOR BURST DEPTH OF $17W^{1/3}$ FEET AT A REFERENCE TIME OF ONE HOUR AFTER BURST

FIGURE 4-24



DEPTH MULTIPLICATION FACTOR FOR LINEAR CONTOUR DIMENSIONS

HARBOR BURST DOSE RATE CONTOUR AREAS

Figure 4–25 presents dose rate contour areas to be expected over adjacent land masses at 1 hour after burst time due to residual radiation resulting from bursting nuclear weapons with yields from 1 KT to 1 MT in a shallow harbor. For this purpose, a harbor depth of 30 to 50 feet of water over a mud bottom is assumed, and the burst is assumed to take place a few feet below the water surface, such as in the hold of a ship. The areas given may be assumed to be independent of wind, although specific location of the contaminated areas with respect to the burst point is a sensitive function of wind and other meteorological conditions, as with other types of contaminating bursts. Area magnitudes may be read directly from the curves for those dose-rate values for which curves are provided. Extrapolation to higher or lower dose rate contour values than covered by the families of curves cannot be done accurately and should not be attempted. To obtain dose rate values for times other than $H+1$ hour, multiplying factors from figure 4–13 should be used.

Example.

Given: A 30 KT harbor burst.

Find: The area of effect for dose rates of 1,000 r/hr or greater at $H+1$ hour.

Solution: Reading directly from figure 4–25, the area for a dose rate of 1,000 r/hr or more at $H+1$ hour for a 30 KT harbor burst is 3.4 (±1.7) square miles. *Answer.*

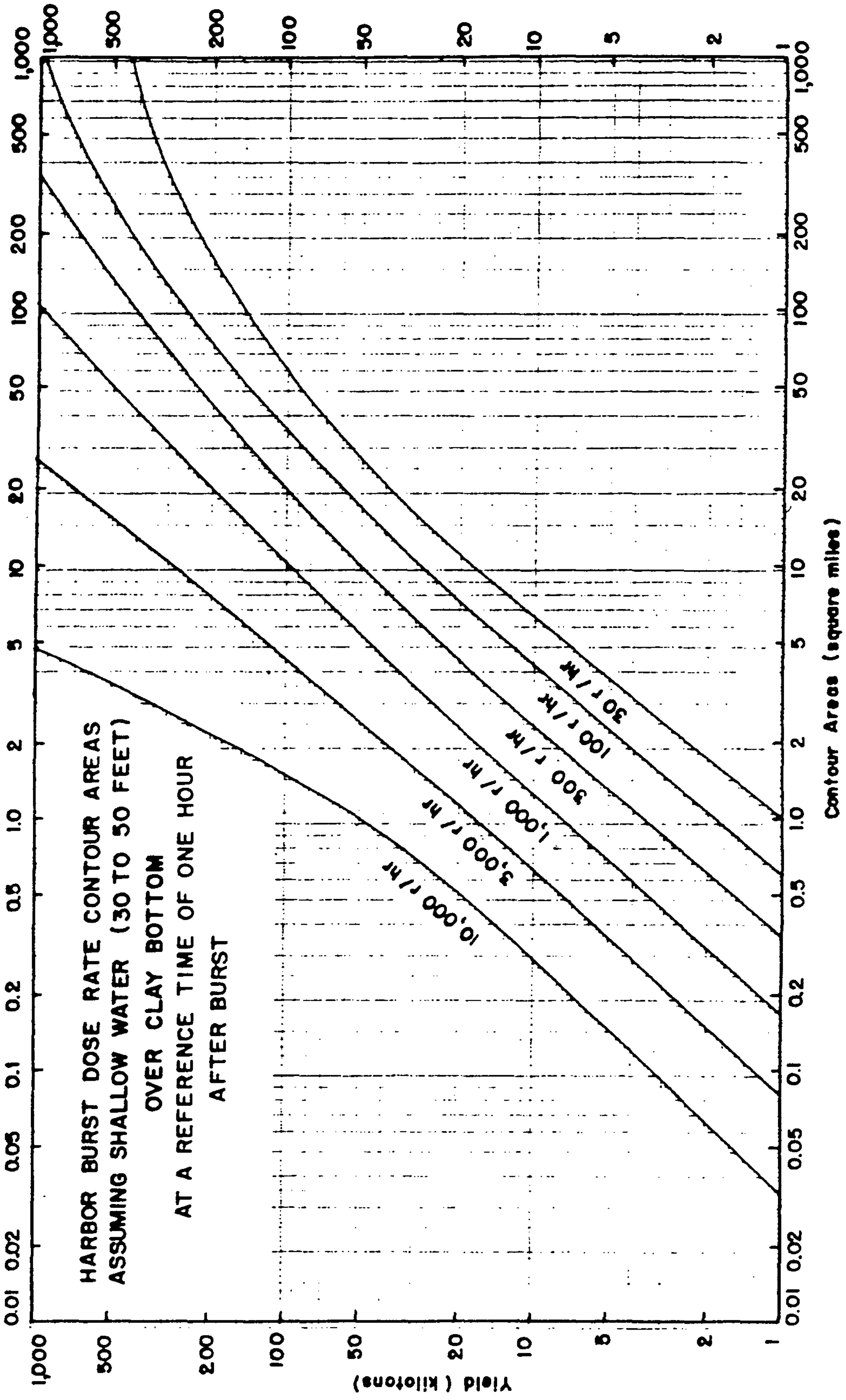
Reliability. Area magnitudes obtained from these curves for a specific yield are considered reliable within ±50 percent for the burst conditions indicated.

Related material.

See paragraph 4.3*e*.

See also figure 4–13 and figure 4–26.

FIGURE 4-25



HARBOR BURST DOSE RATE CONTOUR AREAS ASSUMING SHALLOW WATER (30 TO 50 FEET) OVER CLAY BOTTOM AT A REFERENCE TIME OF ONE HOUR AFTER BURST

TOTAL RADIATION DOSE RECEIVED IN A CONTAMINATED AREA

From figure 4–26 can be obtained the total dose received on entering a given contaminated area at a specified time and remaining for a specified interval of time. The vertical axis gives the accumulated dose for each unit (r/hr) of dose rate at one hour after the detonation. The various curves represent times of stay in the contaminated area. To get the accumulated dose, a factor is taken from the vertical axis corresponding to the time of entry and the time of stay. The product of this factor and the dose rate at one hour gives this accumulated dose.

Example.

Given: The dose rate in a given area at one hour after detonation is 500 r/hr.

Find: The total dose received by a man entering the area two hours after detonation and remaining 4 hours.

Solution: From figure 4–26 the intersection of the line for a time of entry of two hours after detonation with the 4-hour curve gives a factor of 0.80. Therefore, the accumulated dose is—

$$500 \times 0.80 = 400\ r.\quad \textit{Answer.}$$

Related material.

See paragraphs 4.3*c*(1)(*d*) and 4.3*g*.

See also figures 4–13 and 4–27.

Table 4–2. Chemical Composition of Illustrative Soils

Element	Percentage (by weight)			
	Soil type I (Liberia, Africa)	Soil type II (Nevada desert)	Soil type III (lava clay, Hawaii)	Soil type IV (beach sand, Pensacola, Fla.)
Sodium		1.30	0.16	0.001
Manganese	0.008	0.04	2.94	
Aluminum	7.89	6.90	18.79	0.006
Iron	3.75	2.20	10.64	0.005
Silicon	33.10	32.00	10.23	46.65
Titanium	0.39	0.27	1.26	0.004
Calcium	0.08	2.40	0.45	
Potassium		2.70	0.88	
Hydrogen	0.39	0.70	0.94	0.001
Boron				0.001
Nitrogen	0.065		0.26	
Sulfur	0.07	0.03	0.26	
Magnesium	0.05	0.60	0.34	
Chromium			0.04	
Phosphorus	0.008	0.04	0.13	
Carbon	3.87		9.36	
Oxygen	50.33	50.82	43.32	53.332

Thus, it may be possible to obtain better data for a given soil by using data from a different illustrative soil at each of several times of interest.

If a weapon is burst at such a height as to be in the transition zone from the fallout standpoint, the neutron-induced activity generally can be neglected if the burst height is in the lower three quarters of the fallout transition zone. For weapons burst in the upper quarter of the fallout transition zone the neutron-induced activity may not be negligible compared to fallout. For the cases where fallout dose rate contour parameters, as determined from figures 4–14 through 4–18, are much smaller than those for a burst on the surface, an idea of the magnitude of induced activity may be obtained from figures 4–28 through 4–33. The overall contour values may then be obtained by combining the induced activity and fallout activity. For these cases it must be remembered that fission products and induced activity will decay at different rates. This necessitates a determination of the magnitude of each type of activity for each time of interest.

(3) *Surface and subsurface bursts.* For surface and subsurface bursts, the residual radioactive contamination from fission products is vastly greater than the neutron-induced activity. As a result, neutron-induced activity generally can be neglected for surface and subsurface bursts.

j. Residual Beta Radiation. The discussion of residual radiation has thus far considered only gamma radiation. In general, the hazard due to residual gamma radiation exceeds the beta hazard for all cases except those in which intimate contact with beta-active materials occurs, as in the case of a soldier lying prone in a contaminated area, or for particles falling out directly upon the skin or scalp. For such cases, superficial burns may result, the effect of which is discussed in paragraph 6.3*b*(3).

k. Shielding. The dose rates obtained from the contours described, and the total doses derived therefrom, are free field values which must be reduced if the individual concerned is protected by some degree of shelter. Shielding factors can be estimated from the shielding information given in paragraph 6.5. For example, personnel in the open in a built-up city area would receive 0.7 of the free field dose, while

NEUTRON-INDUCED GAMMA ACTIVITY

Given the weapon type and the slant range from the point of burst to the point of interest, the induced gamma dose rates in the vicinity of ground zero at $H+1$ hour can be estimated using figures 4-28A and 4-28B for bursts over soils similar in composition to any of the soils illustrated in table 4-2. To estimate the dose rate, enter the slant range axis with the slant distance in yards, read the dose rate for the appropriate weapon type, and multiply this dose rate by the appropriate factor for the soil type of interest from the following:

Soil type	*Multiplying factor*
I	0.11
II	1.0
III	12.0
IV	0.0026

Scaling. For yields other than 1 KT multiply the dose rate read from the curve by the yield in KT.

Example.

Given: An average neutron flux 50 KT weapon is burst at a height of 900 feet above soil of type III.

Find: The $H+1$ hour dose rate at ground zero and at 600 yards from ground zero.

Solution: From the average neutron flux weapon curve of figure 4-28A the dose rate at $H+1$ hour at ground zero (300 yd. slant range) is 9 r/hr per KT of weapon yield. The multiplying factor for soil type III is 12. Therefore, the dose rate at ground zero one hour after detonation of a 50 KT weapon over soil type III is:

$50 \times 12 \times 9 = 5{,}400$ r/hr. *Answer.*

At 600 yards from ground zero the slant range is 670 yards. From the curve, the induced gamma intensity is 0.35 r/hr per KT of weapon yield at this distance. Therefore, the dose rate 600 yards from ground zero one hour after detonation of a 50 KT weapon over soil type III is:

$50 \times 12 \times 0.35 = 210$ r/hr. *Answer.*

Reliability. Dose rate values taken from the curves for the soils presented are correct to within a factor of 5 for the conditions indicated. For other soils, the data will merely furnish an estimate of the magnitude of the hazard.

Related material.

See paragraph 4.3*i*.

See also figures 4-29 through 4-33.

FIGURE 4-28A

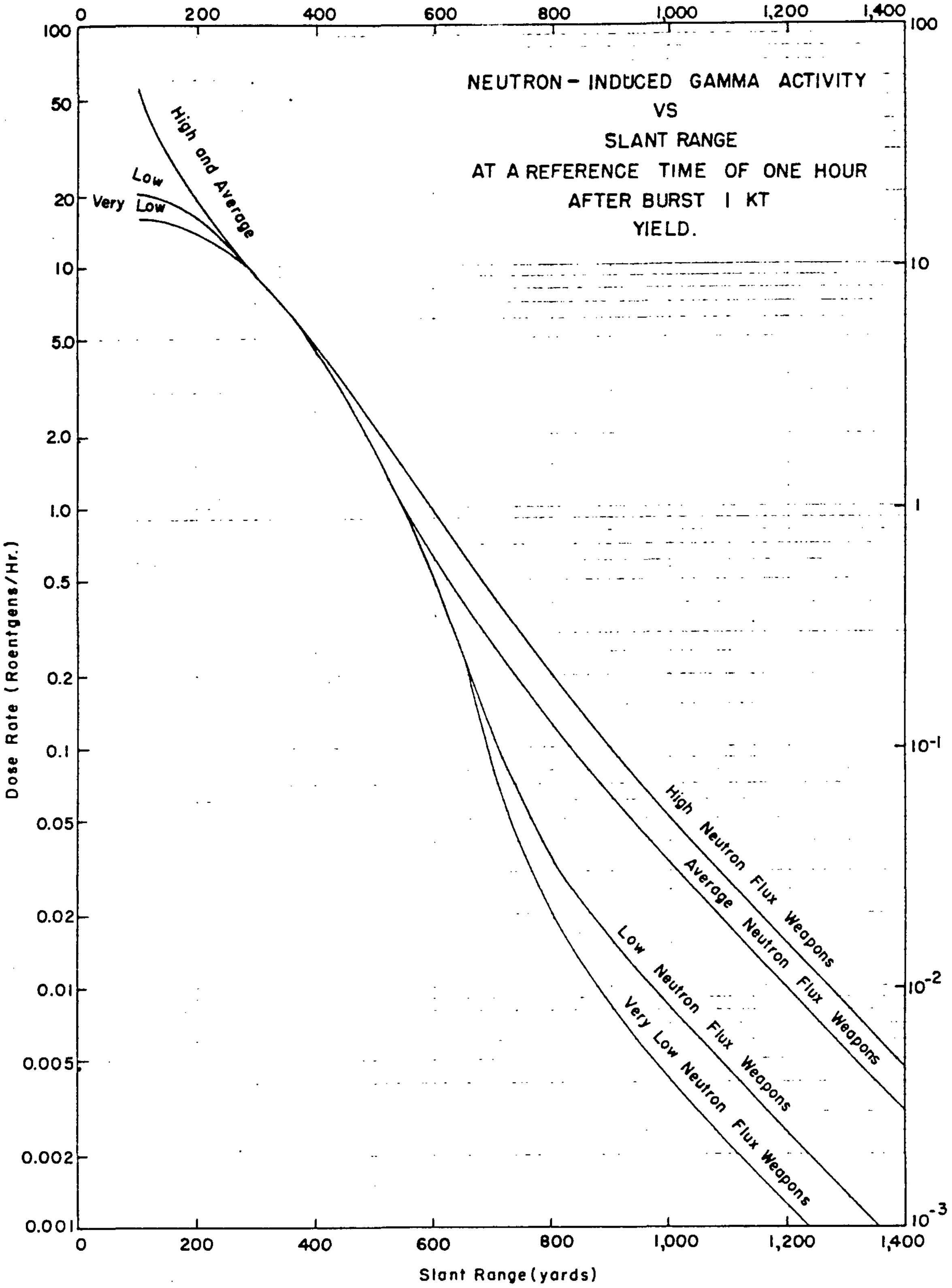
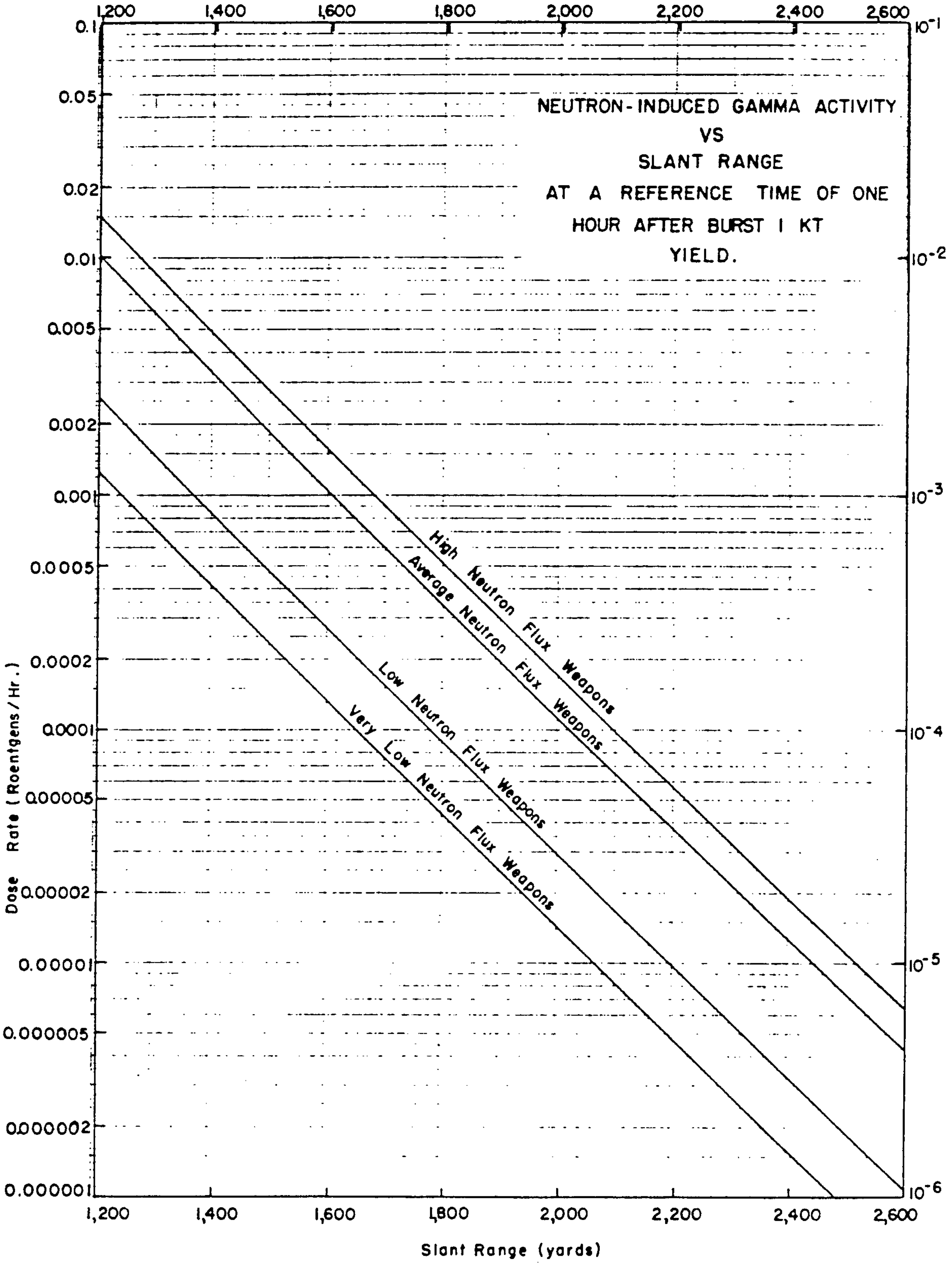

NEUTRON - INDUCED GAMMA ACTIVITY
VS
SLANT RANGE
AT A REFERENCE TIME OF ONE HOUR
AFTER BURST 1 KT
YIELD.
High and Average
Low
Very Low
High Neutron Flux Weapons
Average Neutron Flux Weapons
Low Neutron Flux Weapons
Very Low Neutron Flux Weapons
Dose Rate (Roentgens/Hr.)
Slant Range (yards)
0
200
400
600
800
1,000
1,200
1,400
100
50
20
10
5.0
2.0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
100
10
1
10^{-1}
10^{-2}
10^{-3}

FIGURE 4-28B



1,200
1,400
1,600
1,800
2,000
2,200
2,400
2,600
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
0.00005
0.00002
0.00001
0.000005
0.000002
0.000001
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
NEUTRON-INDUCED GAMMA ACTIVITY
VS
SLANT RANGE
AT A REFERENCE TIME OF ONE
HOUR AFTER BURST 1 KT
YIELD.
High Neutron Flux Weapons
Average Neutron Flux Weapons
Low Neutron Flux Weapons
Very Low Neutron Flux Weapons
Dose Rate (Roentgens/Hr.)
Slant Range (yards)

DECAY FACTORS FOR NEUTRON-INDUCED GAMMA ACTIVITY

From the dose rate at $H+1$ hour, the dose rate at any other time is obtained by computing the product of the appropriate decay factor from figure 4-29 and the 1-hour dose rate.

Example.

Given: The dose rate at a given point on soil type I is 30 r/hr at $H+1$ hour.

Find: The dose rate at that point at $H+1/2$ hour and at $H+10$ hours.

Solution: From figure 4-29 the decay factors for soil type I for 1/2 hour and 10 hours are 3.0 and 0.083 respectively. The dose rate at 1/2 hour is—

$30 \times 3.0 = 90$ r/hr. *Answer,*

and the dose rate at 10 hours is—

$30 \times 0.083 = 2.5$ r/hr. *Answer.*

The decay curves may also be used to determine the value of the dose rate at $H+1$ hour from the dose rate at a later time. In this case, the measured dose rate is divided by the appropriate decay factor.

Example.

Given: The dose rate at a given point on soil type II 20 hours after detonation is 100 r/hr.

Find: The dose rate at the same point 1 hour after the detonation.

Solution: From figure 4-29, the decay factor at 20 hours is 0.24. Therefore, the dose rate at 1 hour is

$\frac{100}{0.24} = 417$ r/hr. *Answer.*

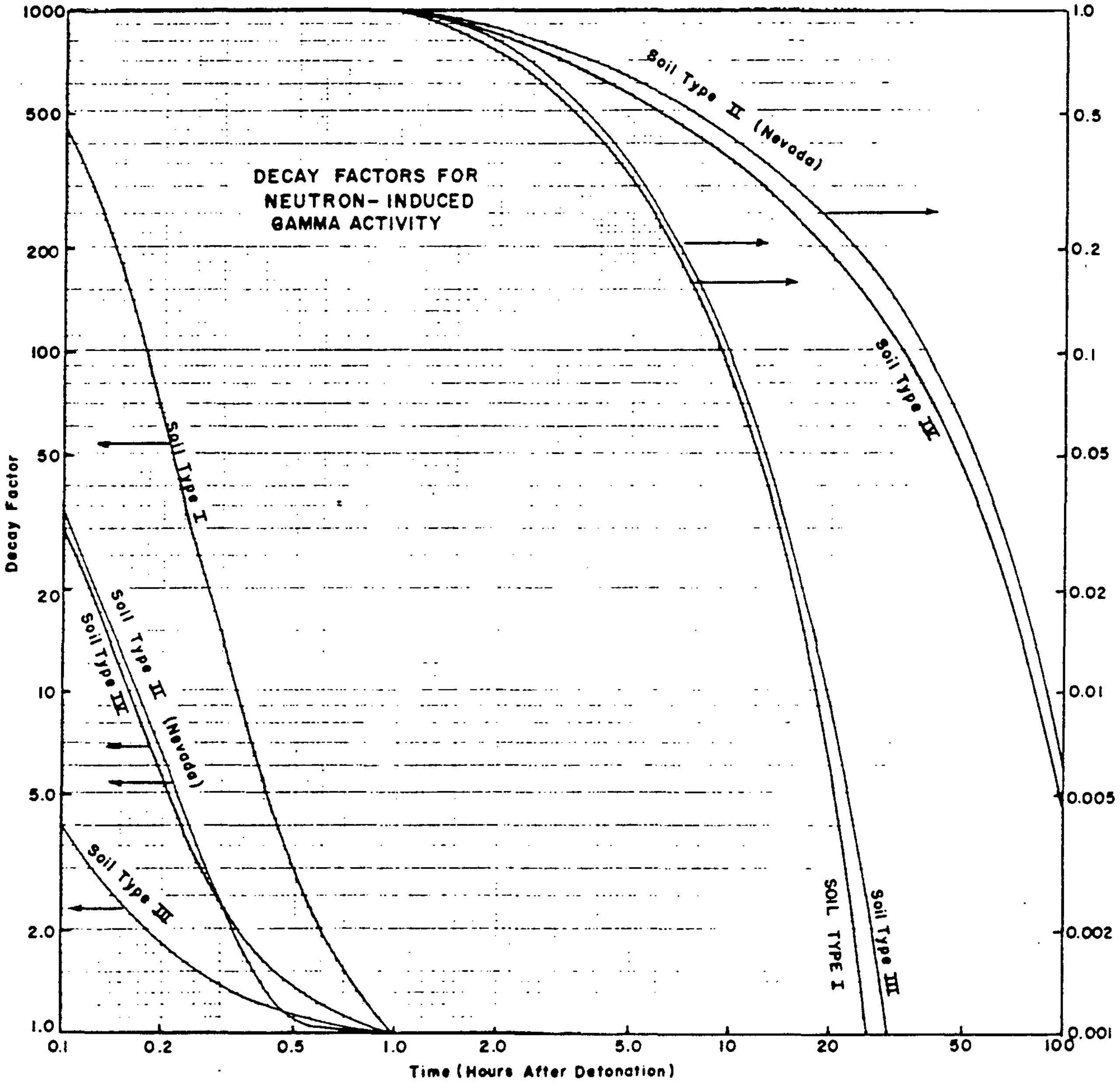
Reliability. The reliability is the same as for figures 4-28A and 4-28B.

Related material.

See paragraph 4.3*i*.

See also figures 4-28A, 4-28B and 4-30 through 4-33.

FIGURE 4-29


DECAY FACTORS FOR
NEUTRON- INDUCED
GAMMA ACTIVITY
Decay Factor
1000
500
200
100
50
20
10
5.0
2.0
1.0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.1
0.2
0.5
1.0
2.0
5.0
10
20
50
100
Time (Hours After Detonation)
Soil Type I
Soil Type II (Nevada)
Soil Type IV
Soil Type III
Soil Type II (Nevada)
Soil Type IV
SOIL TYPE I
Soil Type III

TOTAL-NEUTRON INDUCED GAMMA DOSE FOR VARIOUS SOIL TYPES

From figures 4–30 through 4–33 can be obtained the total dose received on entering a given contaminated area at a specified time and remaining for a specified interval of time. The vertical axes give the accumulated dose for each unit of dose rate (r/hr) at one hour after a detonation over that soil. The various curves represent times of stay in the contaminated area. To get the accumulated dose, a factor is taken from the vertical axis corresponding to the soil type, time of entry and the time of stay. The product of this factor and the dose rate at one hour gives the accumulated dose.

Example.

Given: The dose rate in a given area over soil type III at one hour after detonation is 300 r/hr.

Find: The total dose received by a man entering the area 5 hours after detonation and remaining 1 hour.

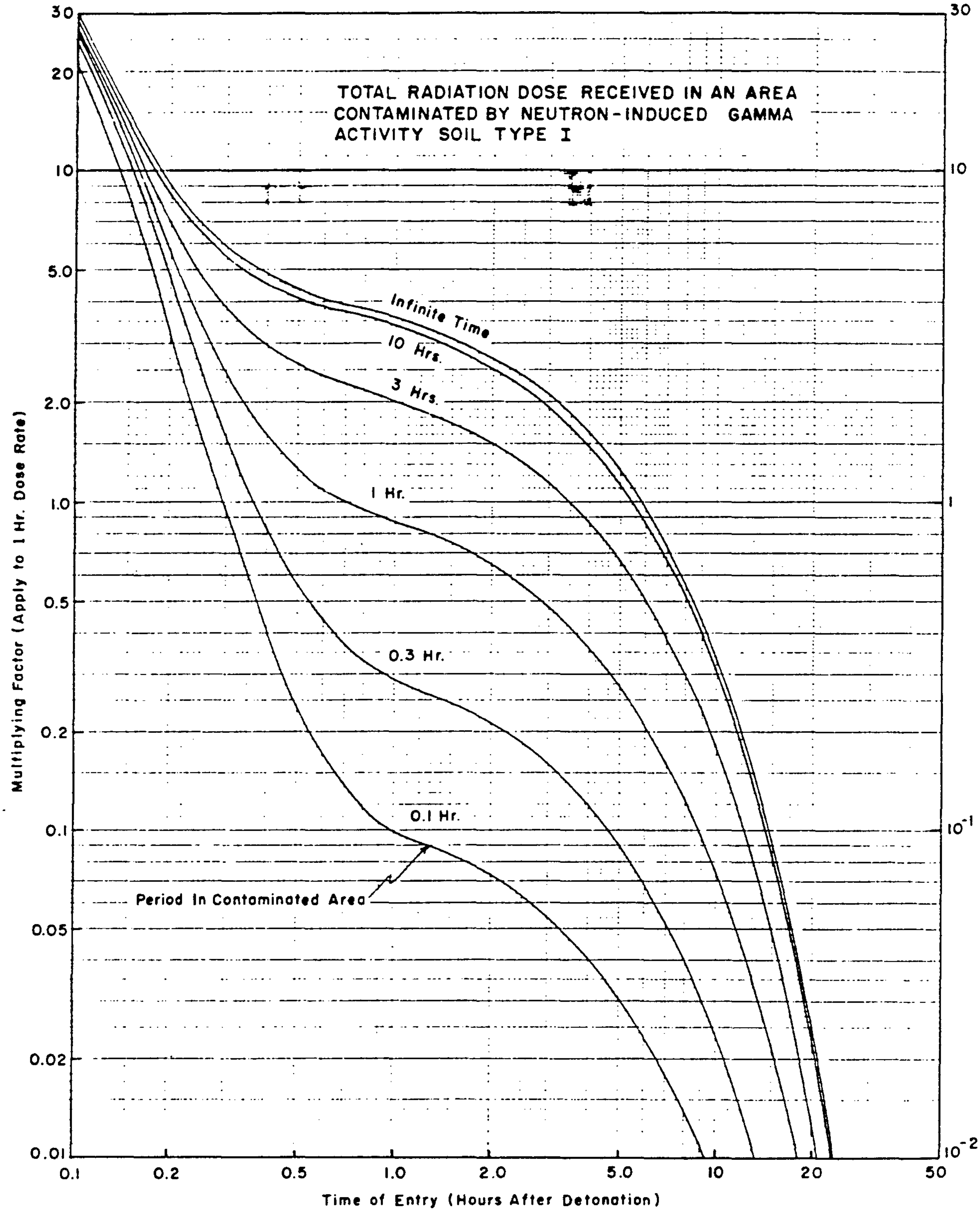
Solution: The proper curves for soil type III are found on figure 4–32. From this figure the intersection of the line for a time of entry of 5 hours after detonation with the 1 hour curve gives a factor of 0.30. Therefore, the accumulated dose is:

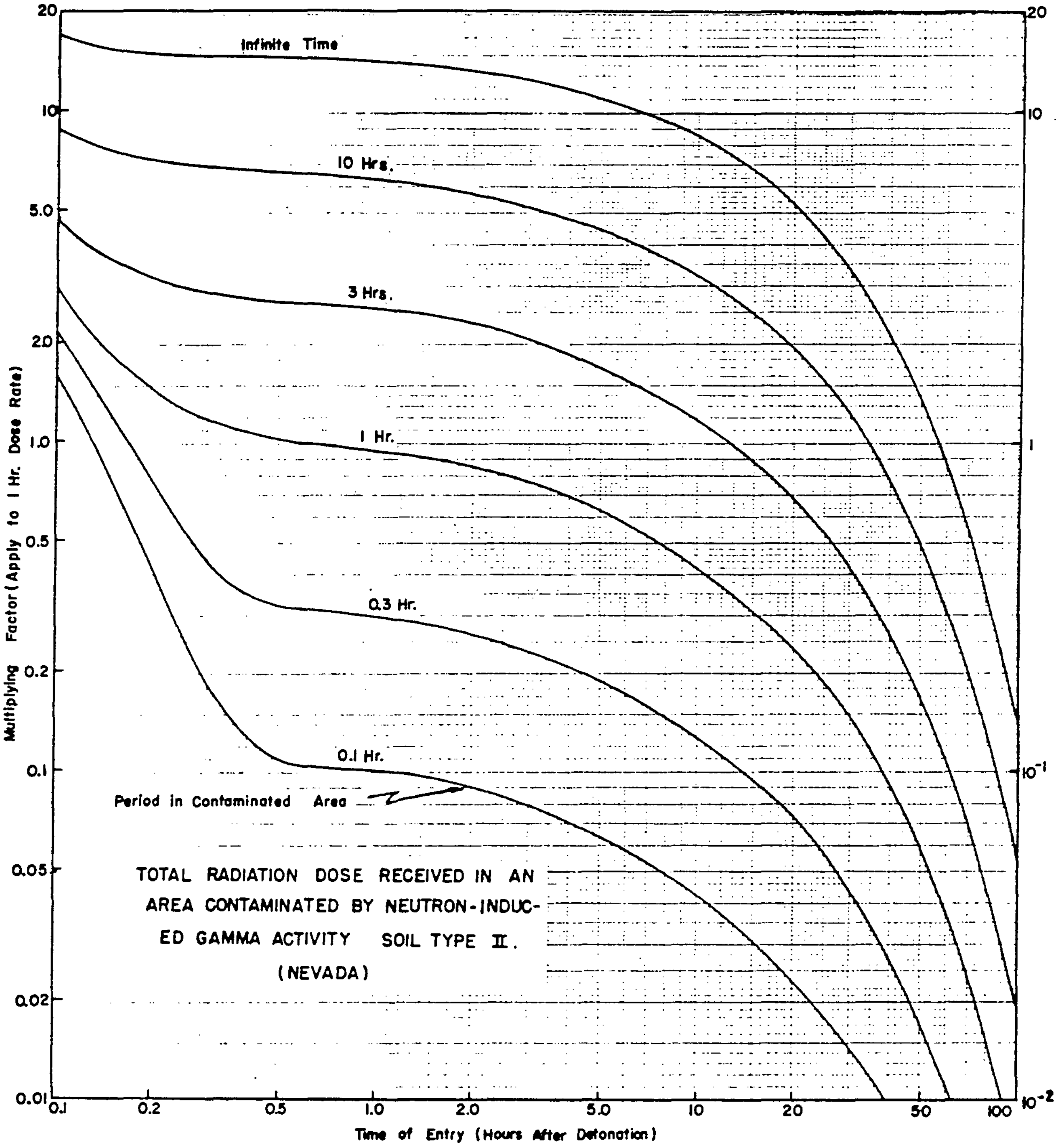
$$300 \times 0.30 = 90\ r.$$

Related material.

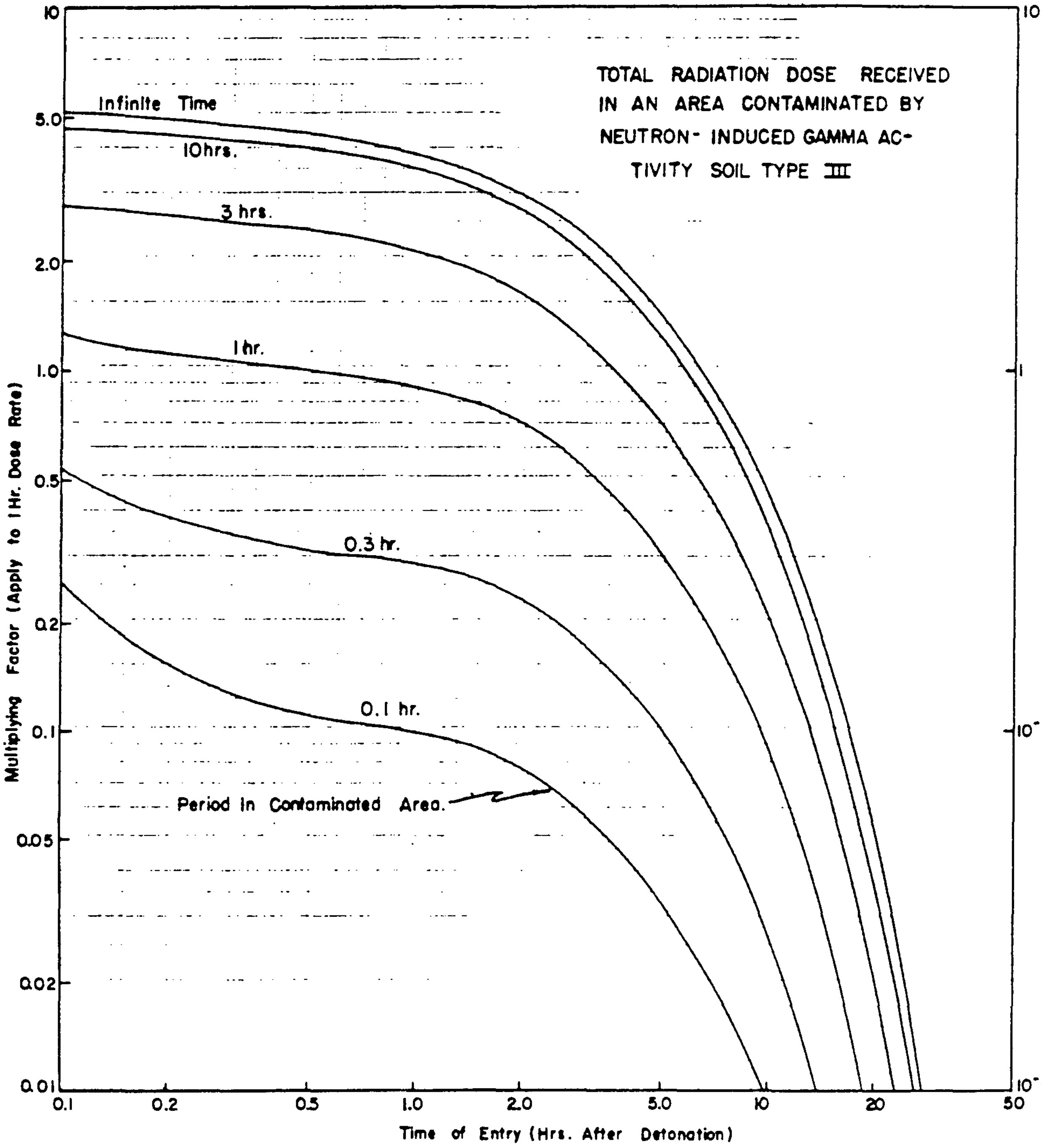
See paragraph 4.3*i*.

See also figures 4–28A, 4–28B and 4–29.


TOTAL RADIATION DOSE RECEIVED IN AN AREA CONTAMINATED BY NEUTRON-INDUCED GAMMA ACTIVITY SOIL TYPE I
Infinite Time
10 Hrs.
3 Hrs.
1 Hr.
0.3 Hr.
0.1 Hr.
Period In Contaminated Area
Multiplying Factor (Apply to 1 Hr. Dose Rate)
Time of Entry (Hours After Detonation)
30
20
10
5.0
2.0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
0.1
0.2
0.5
1.0
2.0
5.0
10
20
50
30
10
1
10^{-1}
10^{-2}

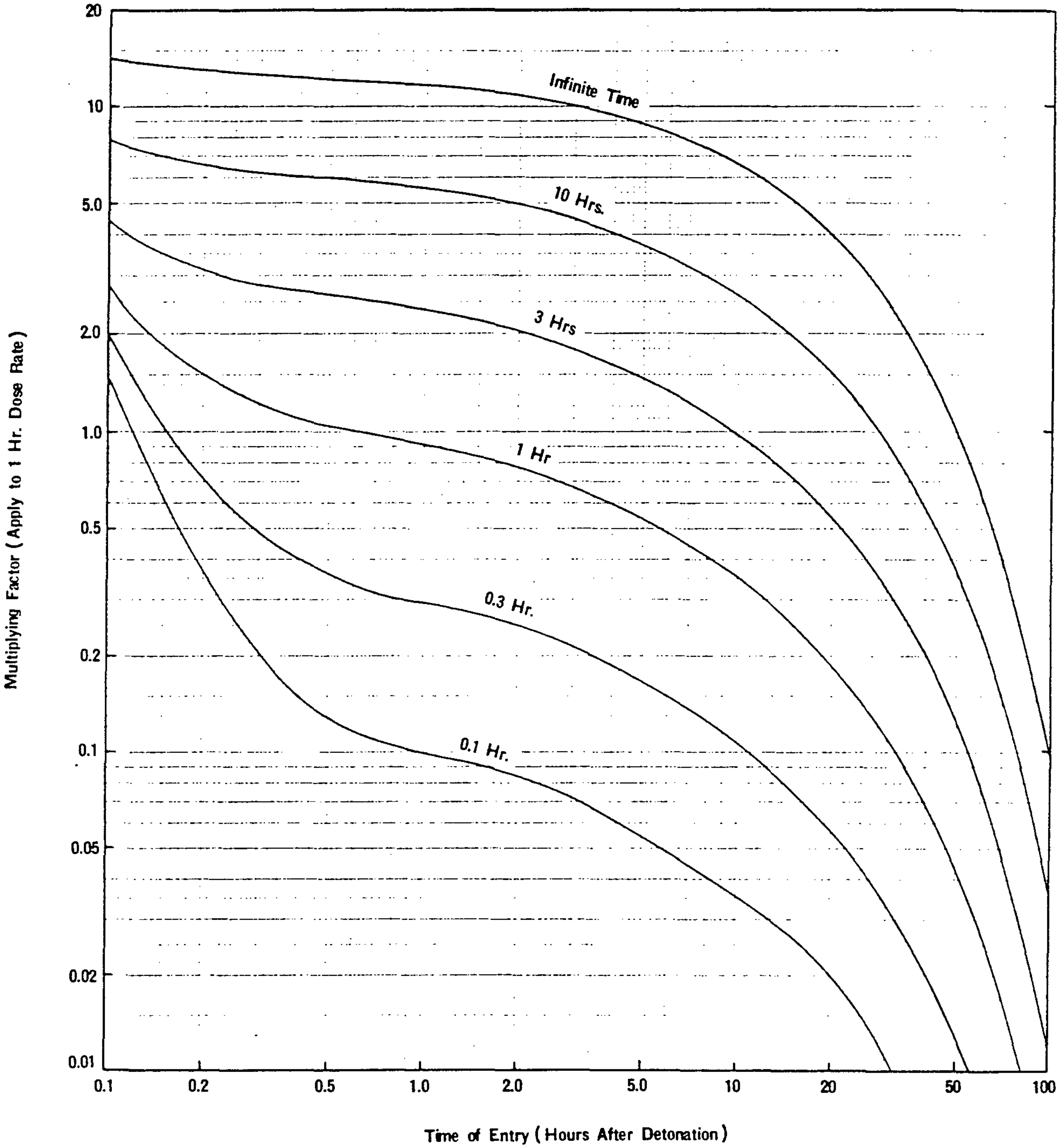


TOTAL RADIATION DOSE RECEIVED IN AN AREA CONTAMINATED BY NEUTRON-INDUCED GAMMA ACTIVITY SOIL TYPE II. (NEVADA)



TOTAL RADIATION DOSE RECEIVED IN AN AREA CONTAMINATED BY NEUTRON- INDUCED GAMMA ACTIVITY SOIL TYPE III

TOTAL RADIATION DOSE RECEIVED IN AN AREA CONTAMINATED BY NEUTRON-INDUCED GAMMA ACTIVITY
SOIL TYPE IV



DOSE RECEIVED WHILE FLYING THROUGH A NUCLEAR CLOUD

The curves of figure 4–37 give the total dose received from passage through nuclear clouds at various times after burst. The relative hazard for flight through the stem is not definitely known; however, flight through the stem is considered somewhat less hazardous than flight through the center of the cloud.

Example.

Given: An aircraft flying at 25,000 feet at a speed of 200 knots is to pass through the center of the cloud from a 50 KT bomb exploded on the surface, which is 1,000 feet above sea level.

Find: The dose which the crew will receive.

Solution: The aircraft will intercept the cloud at—

$$25{,}000-1{,}000=24{,}000 \text{ feet above the burst point.}$$

From figures 4–34 and 4–35 the center of the cloud will reach this altitude above the burst point in 2.8 minutes. At this time after detonation the diameter of the cloud from a 50 KT weapon is 1.5 nautical miles (fig. 4–36). The time spent in the cloud is—

$$\frac{1.5}{200}=0.0075 \text{ hours or } 0.45 \text{ minutes}$$

From figure 4–37 the dose accumulated in the cloud for an entry time of 2.8 minutes and a transit time of 0.45 minutes is 110 *r*. *Answer.*

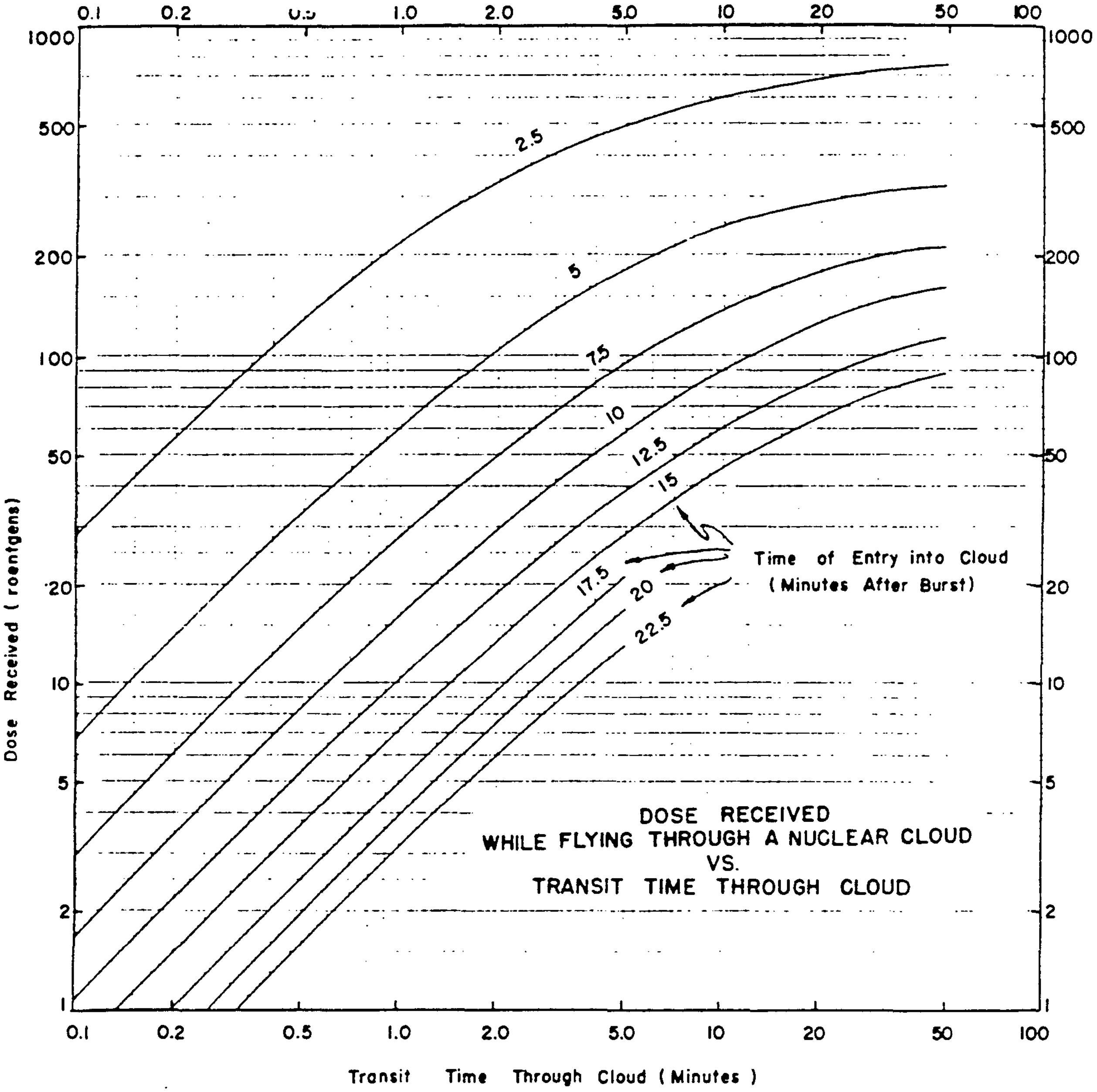
Reliability. The doses indicated are considered accurate within a factor of two for flight paths which pass near the cloud center. For paths close to the cloud boundaries, the predicted dose will probably be higher than the actual dose, although the magnitude of the error is unknown.

Related material.

See paragraph 4.3*l*.

See also figures 4–34 through 4–36.

FIGURE 4-37



DOSE RECEIVED
WHILE FLYING THROUGH A NUCLEAR CLOUD
VS.
TRANSIT TIME THROUGH CLOUD

PHENOMENA AT VARIOUS SCALED BURST HEIGHTS

Figures 5–2A, B, and C show the range from ground zero of various physical phenomena when a burst is on the surface, at a scaled height of 250 $W^{1/3}$ feet, and at a scaled height of 650 $W^{1/3}$ feet, respectively. They are presented primarily for rapid visual comparison of the distance to which the various physical phenomena will extend, and secondarily for a rapid determination of the controlling mechanism of damage at any distance for any yield. From data presented in part one, a similar illustration could be prepared for any scaled or actual burst height.

The significance of the various phenomena curves presented varies with the target being considered. The initial and residual radiation curves are the most significant ones for human targets in the open or in shelters. The values chosen for plotting represent the following:

5 *r*—No obvious effect on personnel.

100 *r*—Non-lethal dose causing sickness in a few personnel, but permitting a unit to remain operationally effective.

450 *r*—Dose lethal within 30 days to 50 percent of personnel exposed.

10,000 *r*—Free field dose which will produce a dose of 100 *r* for personnel within a shelter having a dose transmission factor of 0.01.

The blast and thermal radiation curves cannot be related directly to damage, because of the increasing duration of blast and thermal phenomena with increasing yield and the dependence of the degree of damage sustained on the duration of the damage-producing effect. To assist in relating the curves presented to expected damage, the following table shows the variation with yield of the magnitude of weapon phenomena required to cause various degrees of damage to certain selected targets. (Refer to secs. VI through XII for a more detailed presentation of damage criteria.)

	1 KT	*100 KT*	*10 MT*
Thermal effects:		*(cal/cm²)*	
Second degree bare skin burn	4	5. 1	9. 1
Newspaper ignition	2. 9	5. 1	9. 1
White pine charring	10	18	32
Army khaki summer uniform destruction	18	31	56
Navy white uniform destruction	34	60	109
Blast effects (in the Mach region):			
Severe damage to overpressure sensitive structures:			
		(PSI overpressure)	
Blast-resistant designed buildings	50	40	35
Reinforced concrete buildings	10. 5	9. 5	9
Monumental wall bearing buildings	20	15	15
Wood frame housing	3	3	3
Window pane breakage	0. 5	0. 5	0. 5
Severe damage to dynamic pressure sensitive structures:			
		(PSI dynamic pressure)	
Light steel frame single story buildings	4. 5	2	0. 9
Heavy steel frame single story buildings	6	3	1. 5
Steel frame multistory buildings	7. 5	2. 5	0. 9
150′–250′ span truss bridges	50	8	5. 5

Some curves are extrapolated beyond data presented in part one, since it is felt that the relationships between phenomena as shown will hold in those regions where there is little supporting knowledge, even though the actual values may be questionable. Since thermal curves are extended beyond one-half the visibility, their interpretation in that region must be approached with caution. In figures B and C, the relative air density would decrease as the actual height of burst is increased in a real case. However, it is held constant for illustrative purposes here. The conversion from slant range to ground range, plus the variation in enhancement of gamma radiation, causes the change in the shape of the radiation curves with change of burst height. Fallout contours are elliptical; only the downwind extent is shown.

Reliability. Varies with the phenomenon of interest. See part one.

Related material.

See paragraph 5.5.

than those listed in table 6–1, it is necessary to consider the type of structural damage that occurs and the characteristics of the resultant missiles. Glass breakage extends to considerably greater ranges than almost any other structural damage, and may be expected to produce large numbers of casualties at ranges where personnel are relatively safe from other effects, particularly for an unwarned population.

Table 6–1. Estimated Casualty Production in Structures for Various Degrees of Structural Damage

	Killed outright	Serious injury (hospitalization)	Light injury (No hospitalization)
1–2 story brick homes (high explosive data):	*Percent*	*Percent*	*Percent*
Severe damage	25	20	10
Moderate damage	<5	10	5
Light damage	------	<5	<5
Reinforced-concrete buildings (Japanese data, nuclear):			
Severe damage	100	------	------
Moderate damage	10	15	20
Light damage	<5	<5	15

Note. These percentages do not include the casualties which may result from fires, asphyxiation, and other causes from failure to extricate trapped personnel. The numbers represent the estimated percentage of casualties expected at the maximum range where the specified structural damage occurs. For the distances at which these degrees of damage occur for various yields, see section VII.

(3) *Personnel in vehicles.* Personnel in vehicles may be injured as a result of the response of the vehicle to blast forces. Padding where applicable and the use of safety belts, helmets, and harnesses virtually eliminates this source of casualties, at least within armored vehicles. In the absence of these protective devices, serious lacerations may result from impact with sharp projections within the vehicle interiors. Comparative numbers of casualties are almost impossible to assess in this respect due to the many variables which are involved.

(4) *Personnel in the open.* Missiles translated by the blast wave may be a significant source of injury to exposed personnel. Missiles having low velocities, if of sufficient size, may cause crushing injuries. In contrast, penetrating wounds may be caused by high velocity missiles. The missile density and characteristics are largely a function of the target. Where the target area is relatively clean and there is little material present subject to fragmentation and displacement, fewer injuries from missiles are expected in the open than from debris within structures at comparable distances. When the target complex presents many possible sources of missiles this may not be the case. Personnel in a prone position are less likely to be struck by flying missiles than those who remain standing. Those who succeed in getting into bunkers, foxholes, or in defilade probably will achieve almost complete protection from the flying missile hazard.

6.2 Thermal Injury

a. Introduction. Before attempting to predict the number of thermal casualties which occur in a given situation, it is necessary to recognize the factors which influence the number and distribution of casualties to be expected. These factors include—the distribution or deployment of personnel within the target area, whether proceeding along a road, in foxholes, standing or prone, in the open or under natural cover; orientation with respect to the bomb; clothing, including number of layers, color, weight, and whether the uniform includes helmets, gloves, or other devices which might protect the bare skin, such as flash creams; and natural shielding. These parameters which define the target must be considered along with the factors which define the source of radiation such as yield of the weapon, height of burst, and visibility, as discussed in section III. In many target complexes, a large percentage of thermal casualties may be due to secondary burns. This is particularly true in cities and industrial areas where a major part of the direct radiation may be shielded by intervening structures. Because of the number of factors involved, it is necessary to analyze each particular target situation in order to make realistic predictions of the thermal casualties to be expected.

b. Primary Radiant Energy Burns. Damage to bare skin through the production of burns may be directly related to the radiant exposure and the rate of delivery of the thermal radiation, both of which are yield dependent. For a given total exposure, as the weapon yield increases, the thermal radiation is delivered over a longer period of time and thus at a lower rate. This allows energy loss from the skin surface by conduction to the deeper layers of the skin and by convection to the air. Thus, a given level of damage also is yield dependent. Critical radiant exposures for the production of two degrees of burn on bare skin as a function of yield are presented in figure 6–2 for normal incidence of radiation. Although the data are presented as a single curve, it must be recognized that there will be variations due to factors such as skin color (i. e., darker skin requires a lesser exposure to produce a given severity of burn) and skin temperature (i. e., colder skin as is found in winter or in arctic climates requires a greater exposure to produce the given burn). The curves represent those radiant exposures which will burn 50 percent of any group, including these variants. A first degree burn is defined as one which shows redness; a second degree burn exhibits partial skin destruction or blistering.

c. Burns Under Clothing. Clothing reflects and absorbs much of the thermal radiation incident upon it and thereby protects the wearer against flashburn. In some cases, the protection is complete, but in many cases it is partial in that clothing merely reduces the severity of injury rather than preventing it. At large radiant exposures, there is the additional possibility that the glowing or ignition of the clothing could deliver additional energy to the skin, thereby causing a more severe injury than bare skin would have suffered. There are many factors which contribute to the degree of protection which clothing affords the underlying skin. The thermal resistance of the clothing material itself is probably the most important, as skin burns under undamaged cloth are rarely seen unless the cloth is in close contact with the skin. Other factors are the weight and weave of the fabric; the number of clothing layers worn; the spacing between layers and between the inner layer and the skin; the moisture content, initial temperature, and color of the cloth; the amount and kind of dirt in the cloth; the wind velocity and direction across the surface of the cloth; etc.

The complexity of the interrelations among the above factors makes an accurate prediction extremely difficult. Table 6–2 lists various estimates of radiant exposures required to effect burns under clothing. These values are considered representative of some field conditions, within the limitations due to the varying factors described above.

Table 6–2. Critical Radiant Exposures for Burns Under Clothing

(Expressed in cal/cm² incident on outer surface of cloth)

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform	1°	8	11	14
(2 layers)	2°	20	25	35
Winter Uniform	1°	60	80	100
(4 layers)	2°	70	90	120

Note. These values are sensitively dependent upon many variables which are not easily defined (see text), and are probably correct within a factor of two.

d. The Combat Ineffective. A useful term in the discussion of effects of thermal radiation on personnel is "the combat ineffective." A combat ineffective is defined as a person who, because of his injuries, is no longer capable of carrying out his assigned tasks. This is differentiated from the more common term "casualty," which is defined as an individual whose injuries require medical attention. Damage to certain areas of the body produces a greater number of combat ineffectives than damage to other areas. Burns in the area surrounding the eyes which eventually cause the eyes to swell shut, and burns to the hands which lead to loss of mobility are particularly apt to cause ineffectiveness.

If a sufficient portion of the total body area is burned, physiological shock follows and the individual becomes a casualty. When more than 10 to 15 percent of the total body area receives second degree burns or worse, shock may be expected. The efficacy of injuries to the hands and eyes in producing combat ineffectives, coupled with the vulnerability of these parts due to lack of protection under ordinary circumstances, indicates the importance of providing protection for these areas when nuclear attack is likely. Table 6–3 presents estimates of the production of combat ineffectives by various degrees of thermal injury.

Table 6–5. Dose Transmission Factors (Interior Dose/Exterior Dose)

Geometry	Gamma rays		Neutrons [a]
	Initial	Residual	
Foxholes [b]	0. 05–0. 10	0. 02–0. 10	0. 3
Underground—3 feet	0. 04–0. 05	0. 0002	0. 002–0. 01
Built-up city area (in open)	....	0. 7	....
Frame house	0. 9	0. 3–0. 6	0. 9–1. 0
Basement	0. 05–0. 5	0. 05–0. 10	0. 1–0. 8
Multistory building:			
Upper	0. 9	0. 01	0. 9–1. 0
Lower	0. 3–0. 6	0. 1	0. 9–1. 0
Blockhouse walls:			
9 inches	0. 1	0. 05	0. 3–0. 5
12 inches	0. 05–0. 09	0. 01–0. 02	0. 2–0. 4
24 inches	0. 01–0. 03	0. 001–0. 002	0. 1–0. 2
Factory, 200 x 200 feet	....	0. 10–0. 20	....
Shelter, partly above grade:			
With earth cover—2 feet	0. 02–0. 04	0. 005–0. 02	0. 02–0. 08
With earth cover—3 feet	0. 01–0. 02	0. 001–0. 005	0. 01–0. 05
[redacted]			
LVT (Landing Vehicle Tracked)	0. 5–0. 9	....	1. 0
Battleships and large carriers [c]:			
15% of crew	1. 0	1. 0	0. 8–1. 0
25% of crew	0. 2	0. 1	0. 2–0. 8
10% of crew	0. 05	0. 03	0. 05–0. 2
50% of crew	0. 0005–0. 005	0. 0003–0. 003	0. 001–0. 05
Cruisers and carriers [c]:			
10% of crew	1. 0	1. 0	0. 8–1. 0
20% of crew	0. 5	0. 3	0. 4–0. 8
30% of crew	0. 1–0. 3	0. 1	0. 1–0. 4
40% of crew	0. 005–0. 1	0. 003–0. 05	0. 01–0. 1
Aircraft	1. 0	....	1. 0
Destroyers, transports, and escort carriers [c]:			
10% of crew	1. 0	1. 0	0. 8–1. 0
20% of crew	0. 7	0. 5	0. 6–0. 8
30% of crew	0. 4	0. 2	0. 3–0. 6
40% of crew	0. 1–0. 4	0. 1	0. 1–0. 3

ARMY (b)(1)

[a] Estimated values.

[b] No line-of-sight radiation received.

[c] Crew at General Quarters.

SHIELDING FROM INITIAL AND RESIDUAL GAMMA RADIATION

The curves in figures 6-5 and 6-6 indicate dose transmission factors for bomb initial and residual gamma radiation, respectively, perpendicularly incident upon various thicknesses of earth, water, concrete, iron, and lead. For other materials of known density, the transmission factor may be estimated by interpolation, on a density basis, between the curves given.

Example.

Find: How much concrete would be required to reduce the dose from initial radiation to one one-hundredth the unshielded dose?

Solution: Examine the curve for concrete of figure 6-5. It is seen that the thickness of a slab of concrete required to reduce the dose to 0.01 of its former value is 34 inches. *Answer.*

Reliability. Thicknesses indicated for a given transmission factor are considered reliable within ±20 percent, for conditions outlined in paragraph 6.5.

Densities of Certain Materials
(Expressed in pounds per cubic foot)

Brick, common	120
Clay, dry	63
Clay, damp, plastic	110
Clay and gravel, dry	100
Coal, piled	40-50
Earth, dry, loose	76
Earth, dry, packed	95
Earth, moist, loose	78
Earth, moist, packed	96
Earth, mud, packed	115
Fuel oil	54
Granite	175
Limestone	165
Masonry, stone	150
Sand, gravel, dry packed	100-120
Fir	34
Hemlock	29
Oak	46
Pine, white	26
Pine, yellow	40

Related Material.

See paragraph 6.5. For radiation input data, see figures 4-1 through 4-7 for air and surface burst initial gamma. Figures 4-28 through 4-33, neutron induced gamma activity. Figures 4-14 through 4-19, surface burst residual gamma. Figure 4-8, underground burst, initial gamma. Figures 4-20 through 4-23, underground residual gamma. Figure 4-25, harbor burst, residual gamma.

FIGURE 6-5

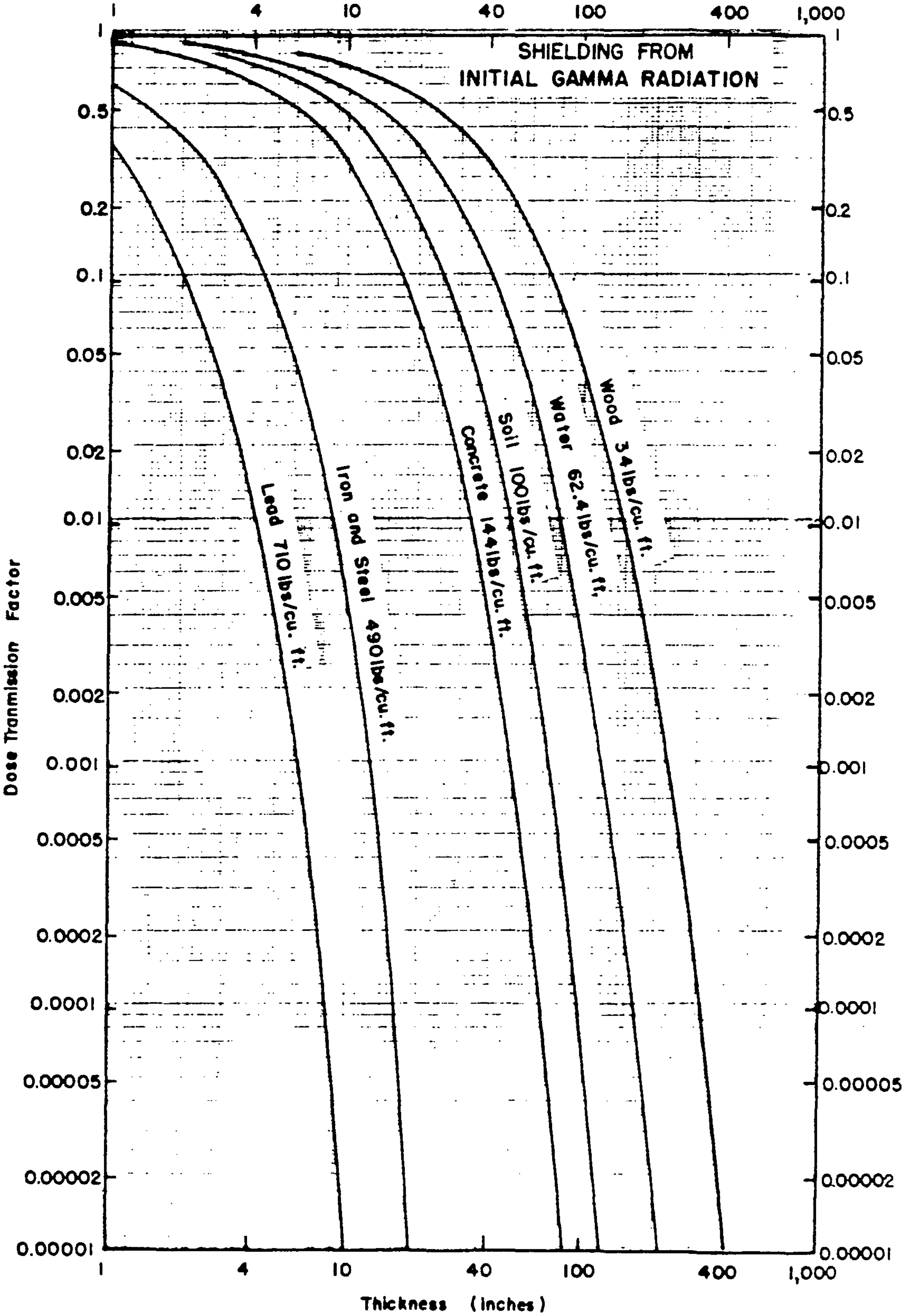

SHIELDING FROM
INITIAL GAMMA RADIATION
Dose Tranmission Factor
Thickness (inches)
1
4
10
40
100
400
1,000
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
0.00005
0.00002
0.00001
Lead 710lbs/cu. ft.
Iron and Steel 490lbs/cu. ft.
Concrete 144lbs/cu. ft.
Soil 100lbs/cu. ft.
Water 62.4lbs/cu. ft.
Wood 34lbs/cu. ft.

FIGURE 6-6

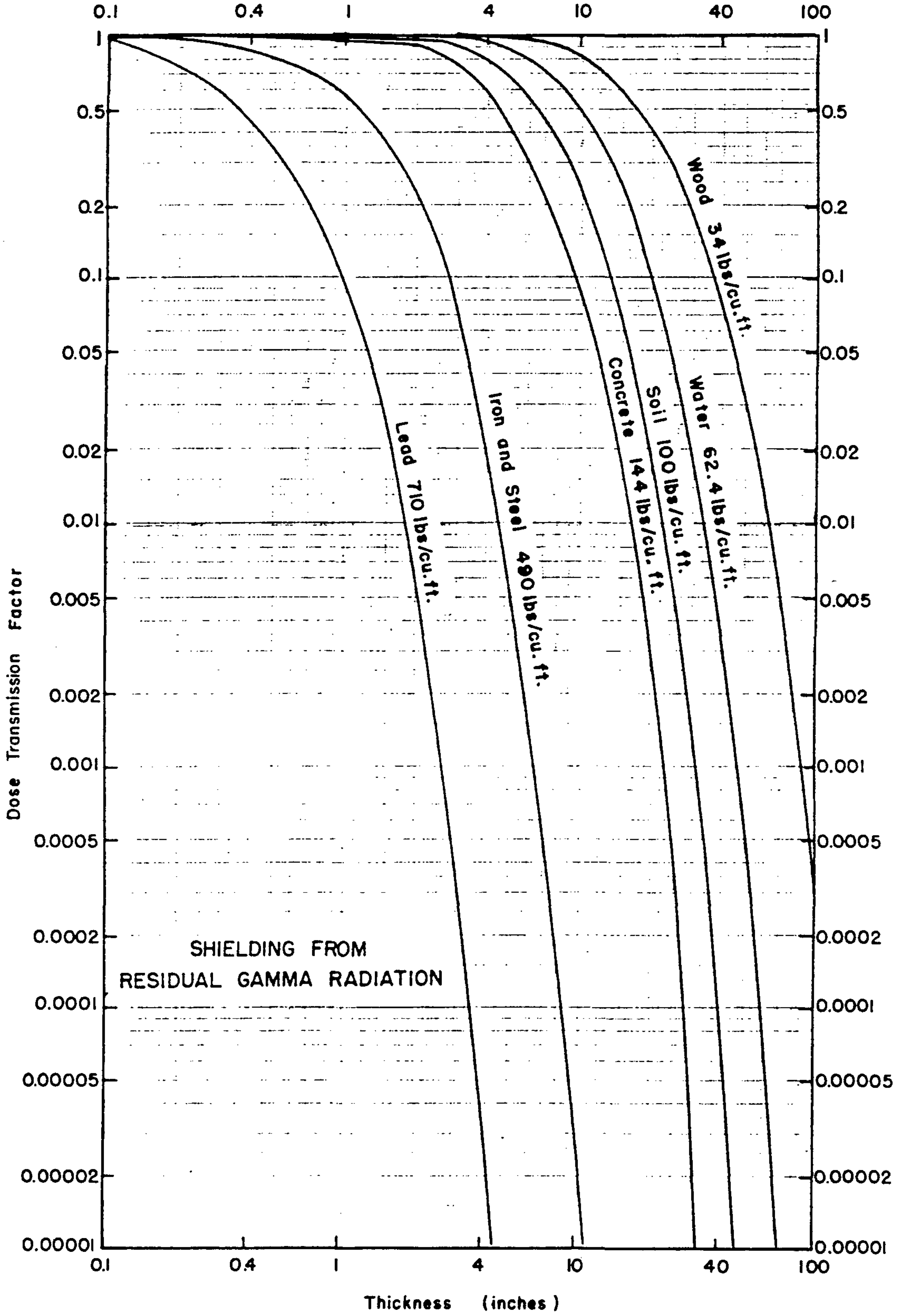

SHIELDING FROM
RESIDUAL GAMMA RADIATION
Dose Transmission Factor
Thickness (inches)
0.1
0.4
1
4
10
40
100
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
0.00005
0.00002
0.00001
Lead 710 lbs/cu. ft.
Iron and Steel 490 lbs/cu. ft.
Concrete 144 lbs/cu. ft.
Soil 100 lbs/cu. ft.
Water 62.4 lbs/cu. ft.
Wood 34 lbs/cu. ft.

FIGURE 7-2A
FIGURE 7-2B

SEVERE DAMAGE TO MULTISTORY REINFORCED CONCRETE BUILDINGS WITH CONCRETE WALLS AND SMALL WINDOW AREA BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

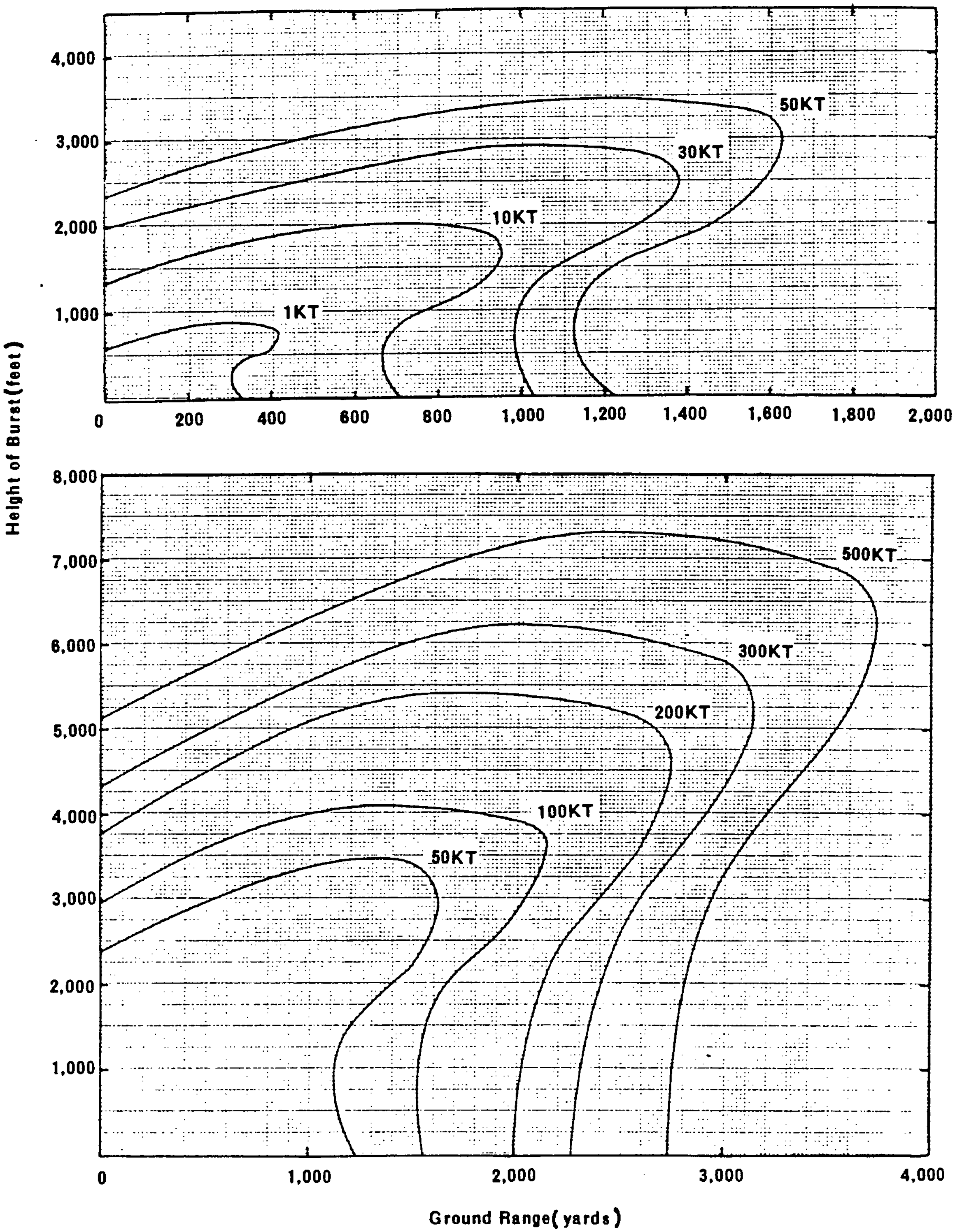
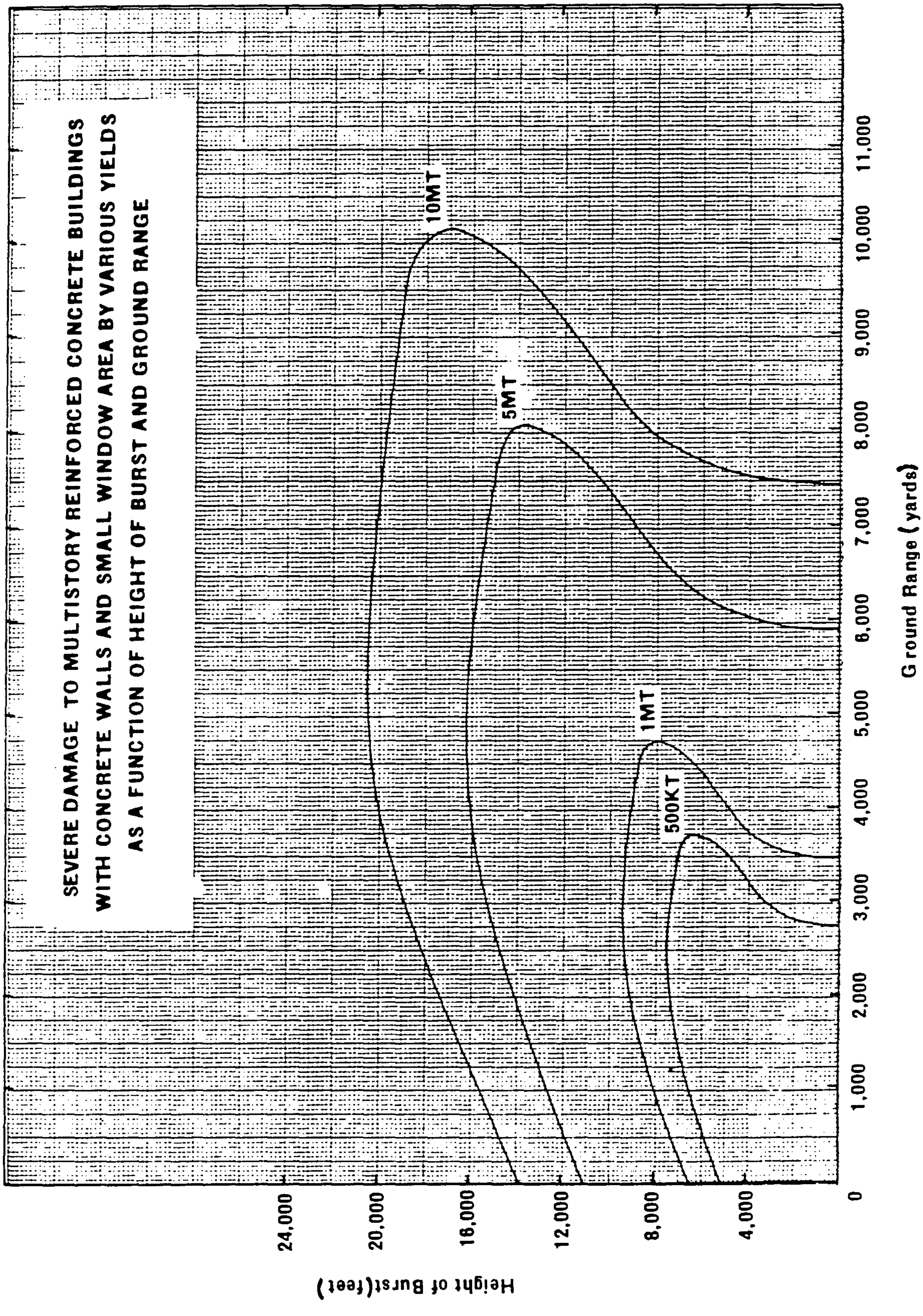


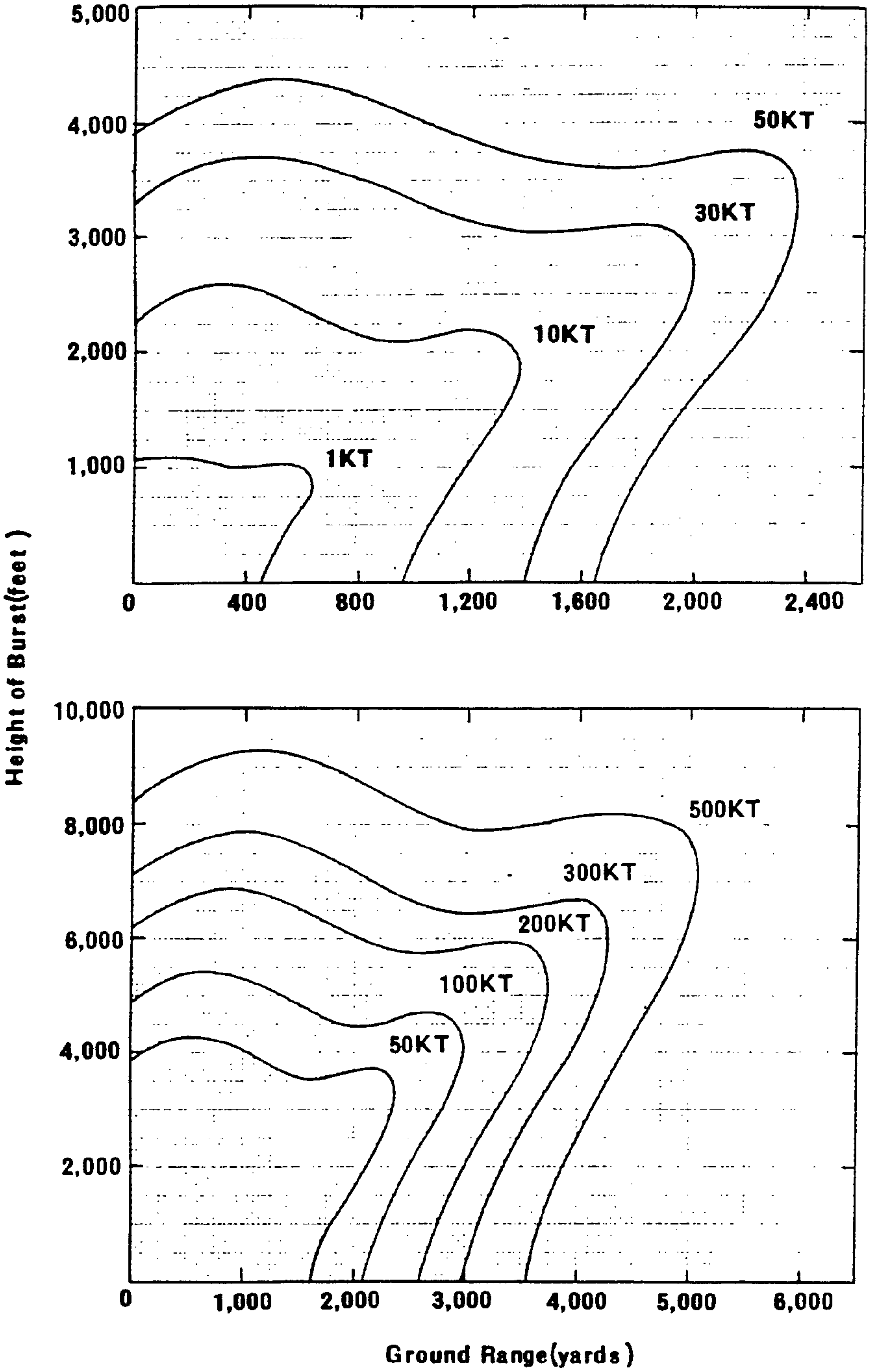
FIGURE 7-2C



SEVERE DAMAGE TO MULTISTORY REINFORCED CONCRETE BUILDINGS WITH CONCRETE WALLS AND SMALL WINDOW AREA BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

FIGURE 7-3A
FIGURE 7-3B

SEVERE DAMAGE TO MULTISTORY WALL BEARING BUILDINGS
BRICK APARTMENT HOUSE TYPE WITH SMALL WINDOW AREA
BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO MULTISTORY WALL BEARING BUILDINGS BRICK APARTMENT HOUSE TYPE WITH SMALL WINDOW AREA BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

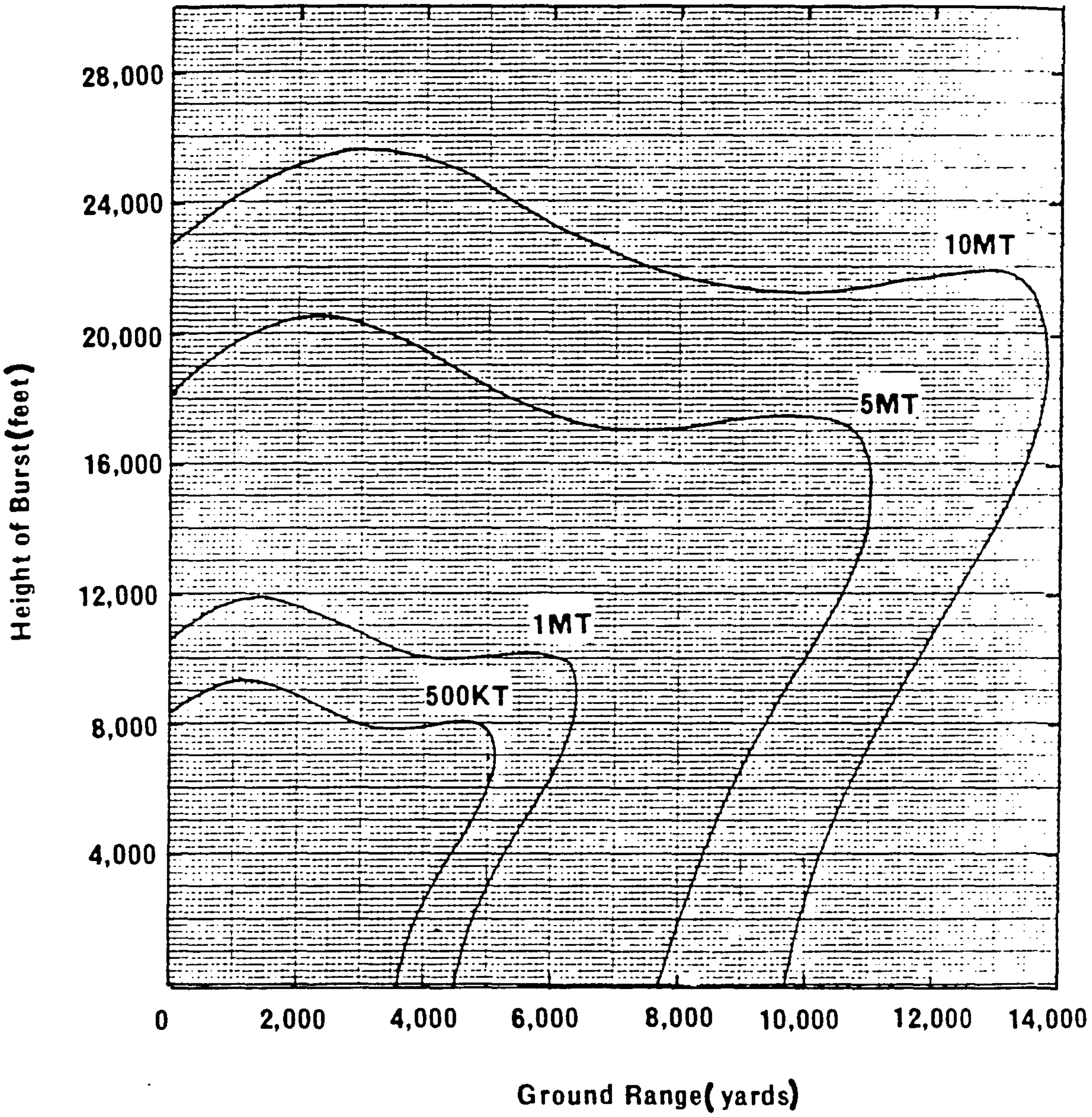
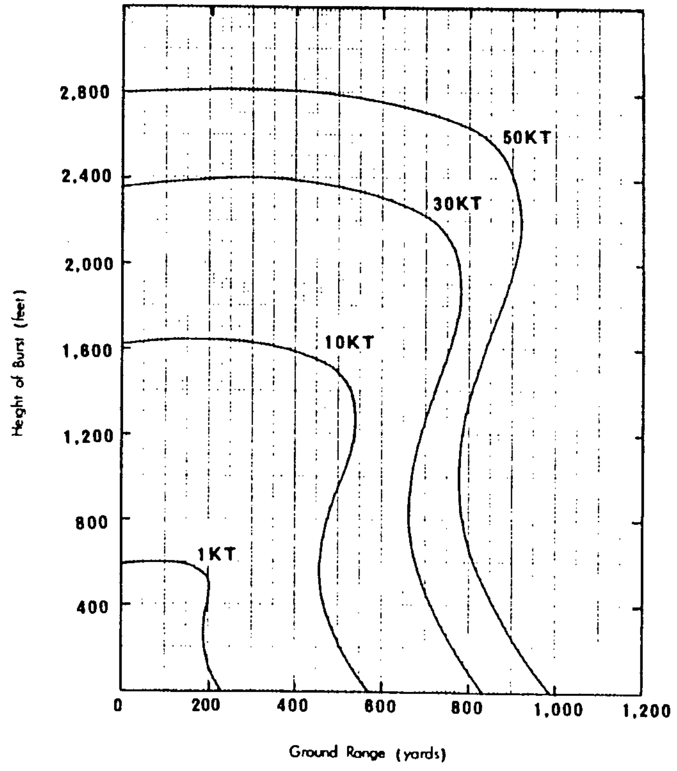
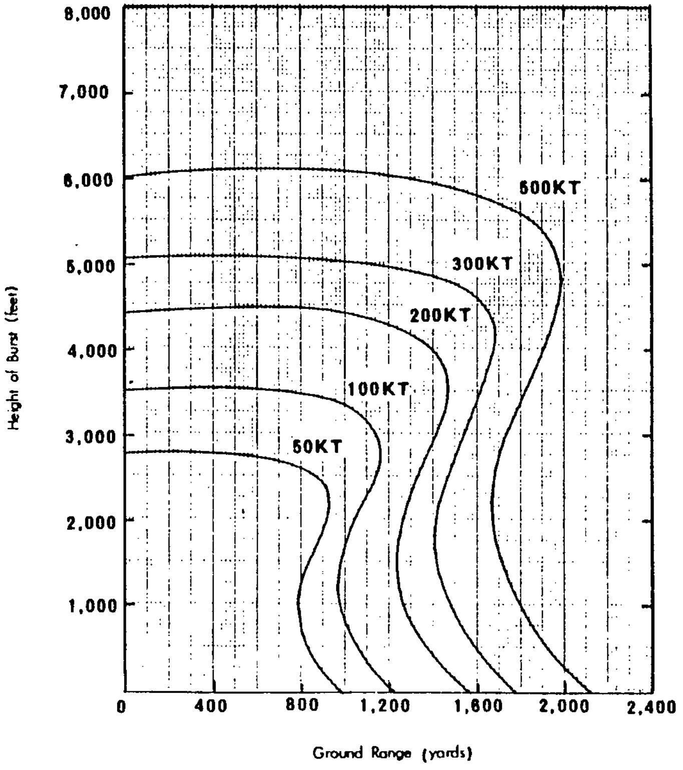


FIGURE 7-4A
FIGURE 7-4B

SEVERE DAMAGE TO MONUMENTAL TYPE MULTISTORY
WALL-BEARING BUILDINGS BY VARIOUS YIELDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE





SEVERE DAMAGE TO MONUMENTAL TYPE MULTISTORY WALL-BEARING BUILDINGS BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

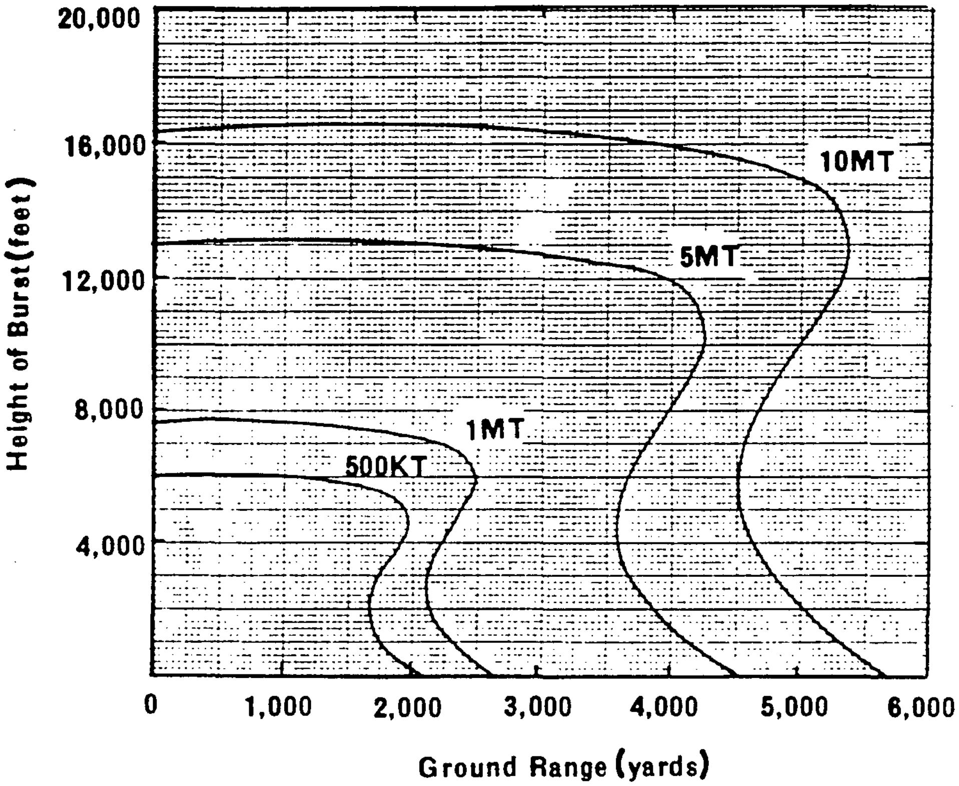


FIGURE 7-5A
FIGURE 7-5B

SEVERE DAMAGE TO WOOD FRAME BUILDINGS BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

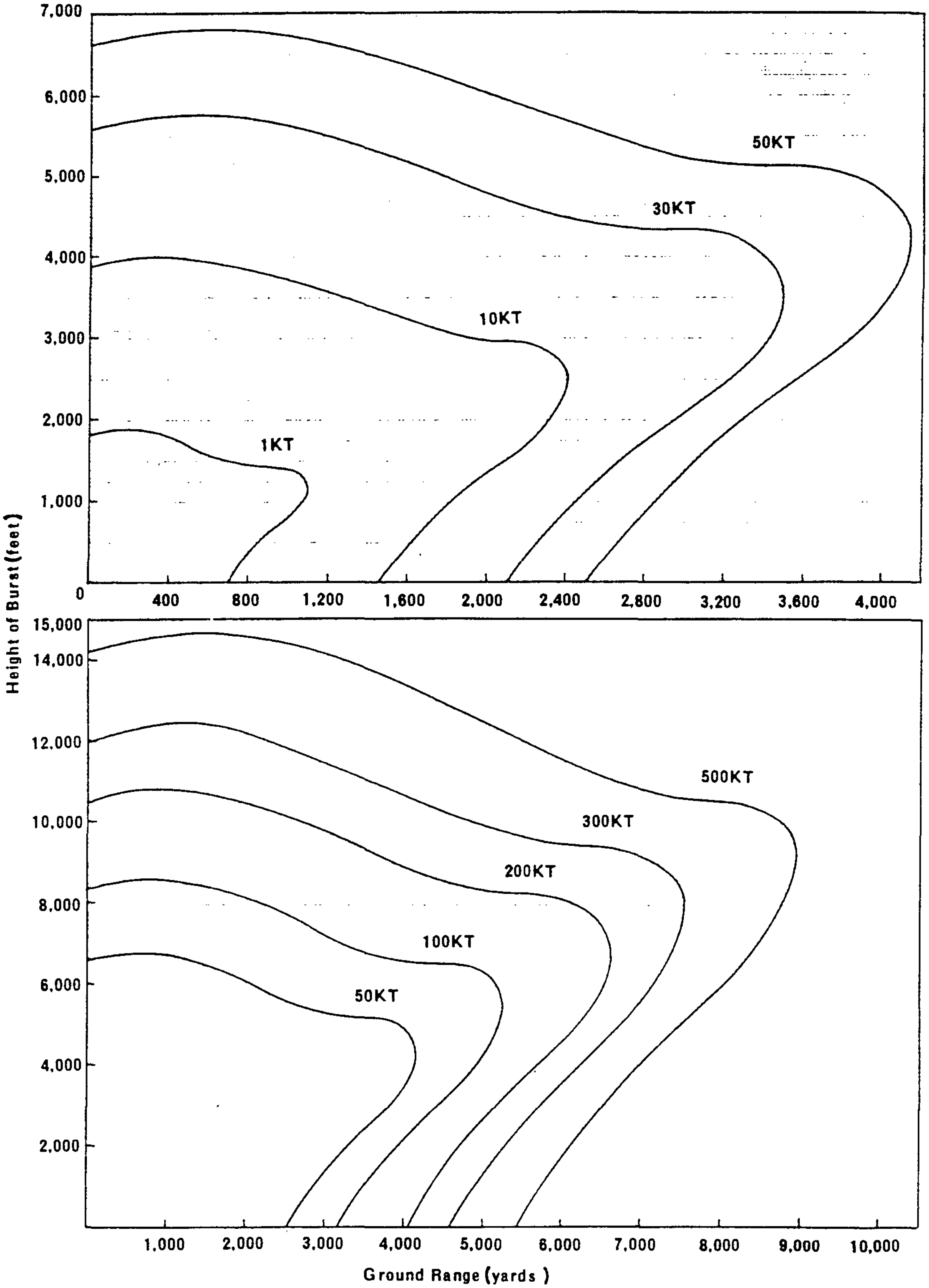
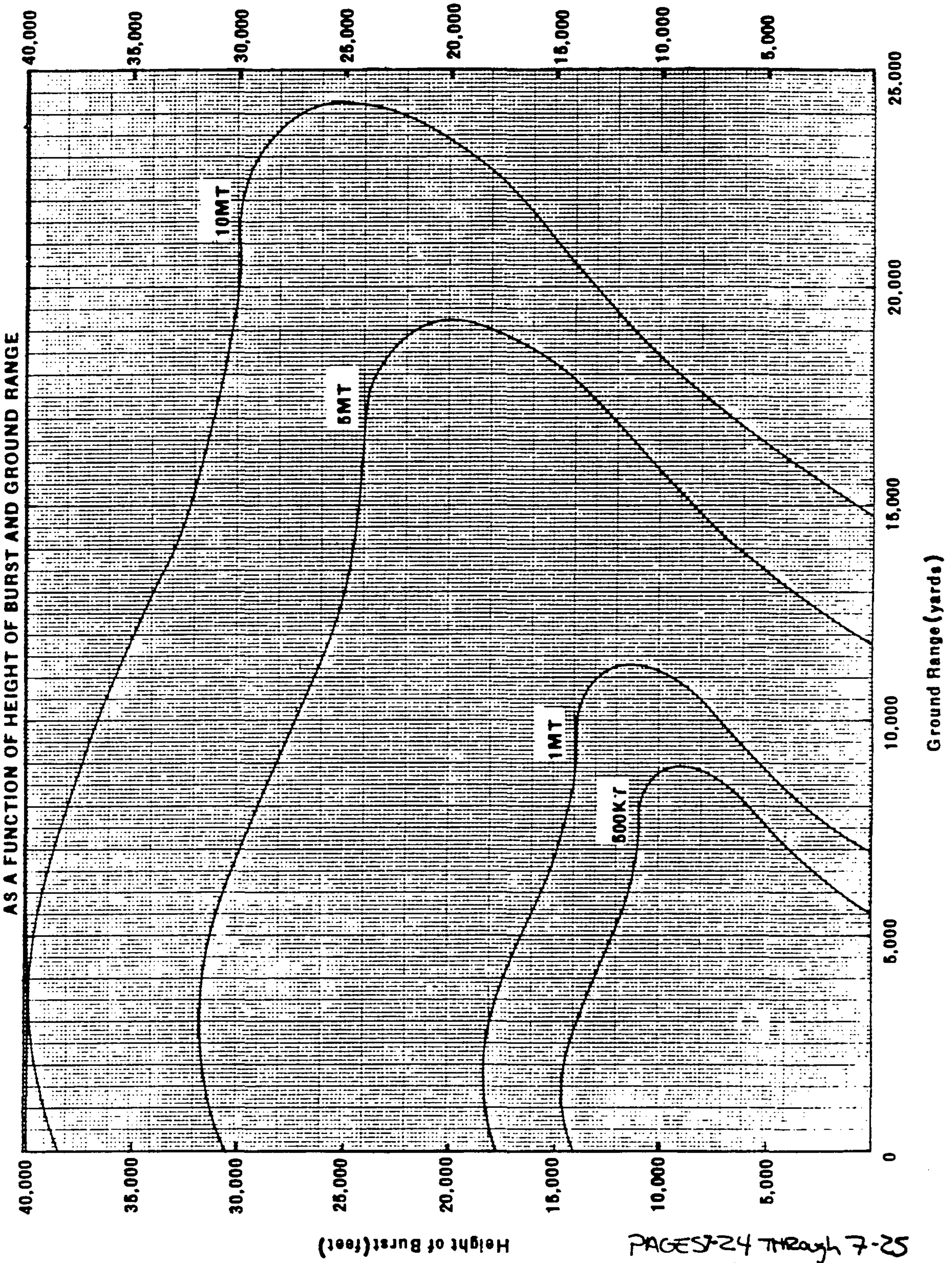


FIGURE 7-5C

SEVERE DAMAGE TO WOOD FRAME BUILDINGS BY VARIOUS YIELDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



PAGES 7-24 Through 7-25
WITHHEID IN THEIR
ENTIRETY (ARMY(b)(1))

FIGURE 7-9A
FIGURE 7-9B

SEVERE DAMAGE TO MULTISTORY STEEL FRAME OFFICE BUILDING BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

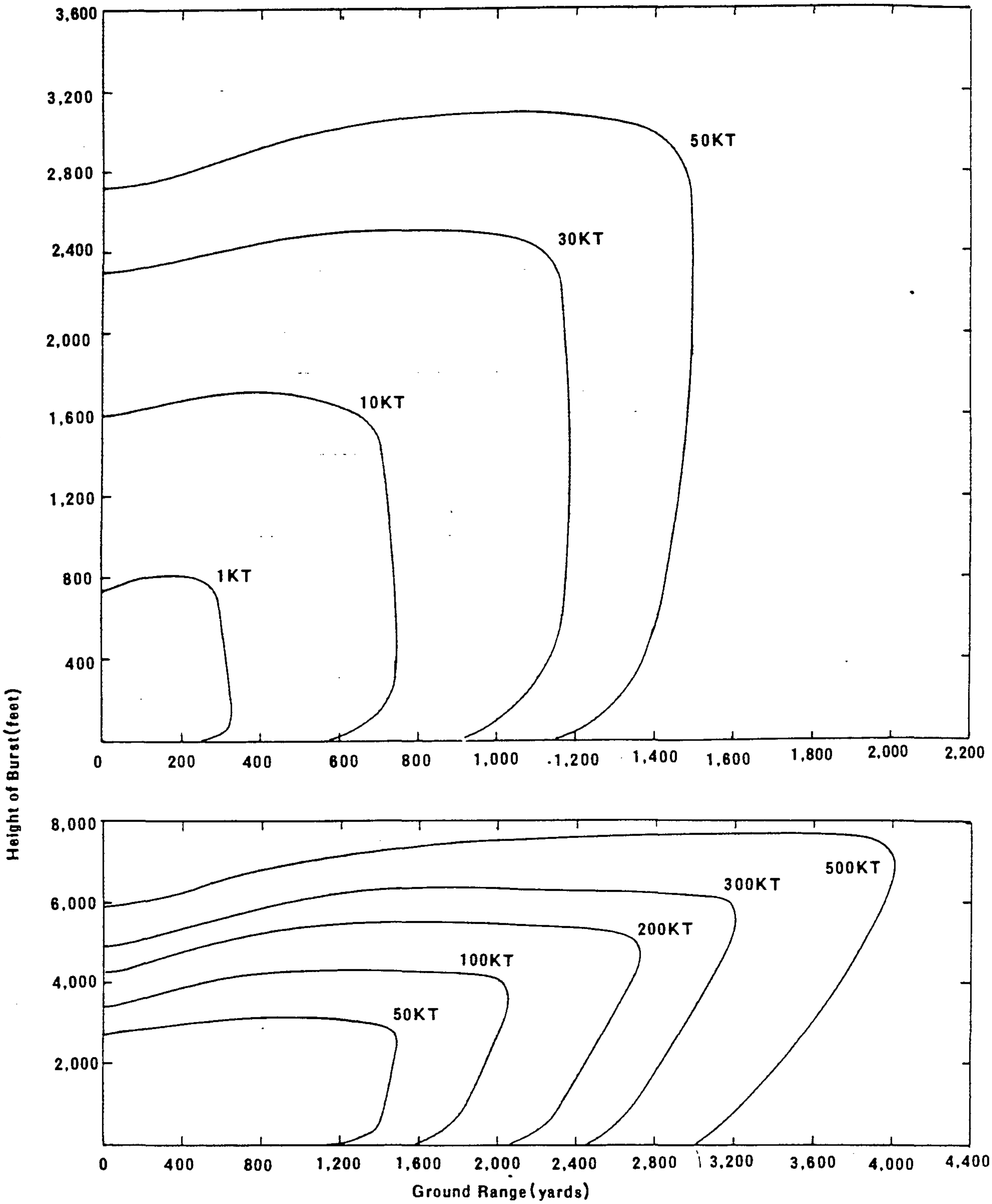
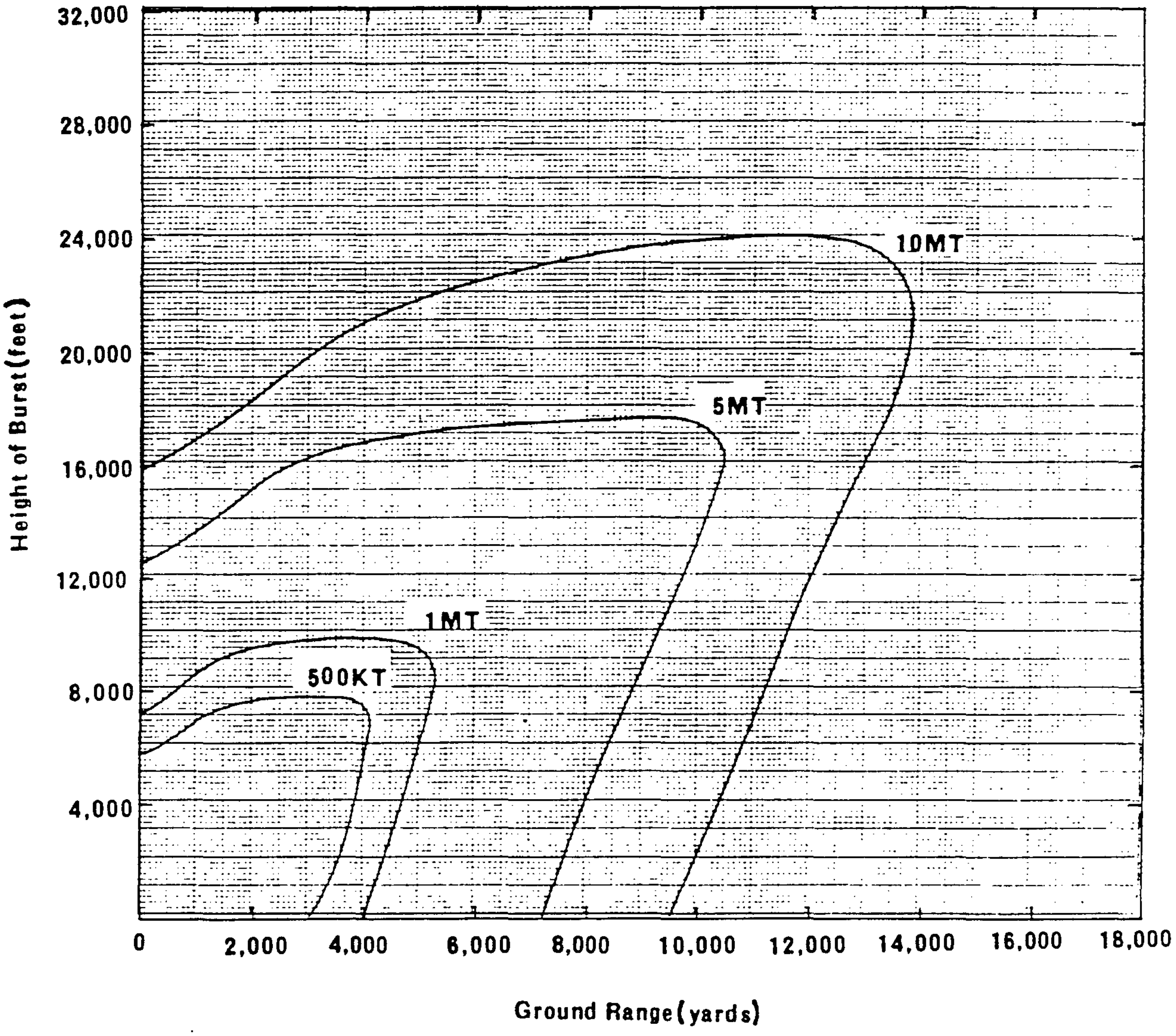


FIGURE 7-9C

SEVERE DAMAGE TO MULTISTORY STEEL FRAME OFFICE BUILDING BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO REINFORCED CONCRETE FRAME OFFICE BUILDINGS BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

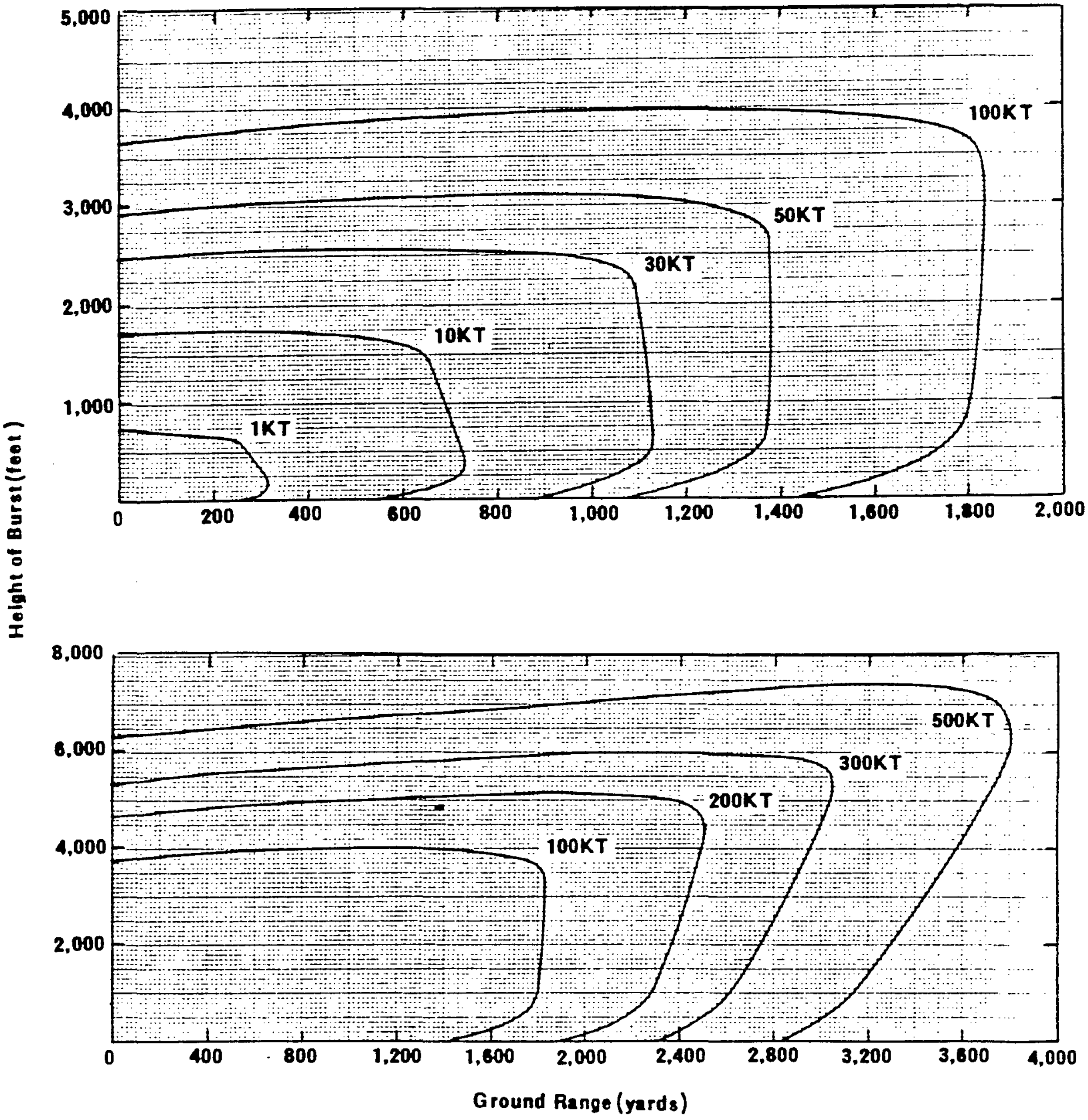
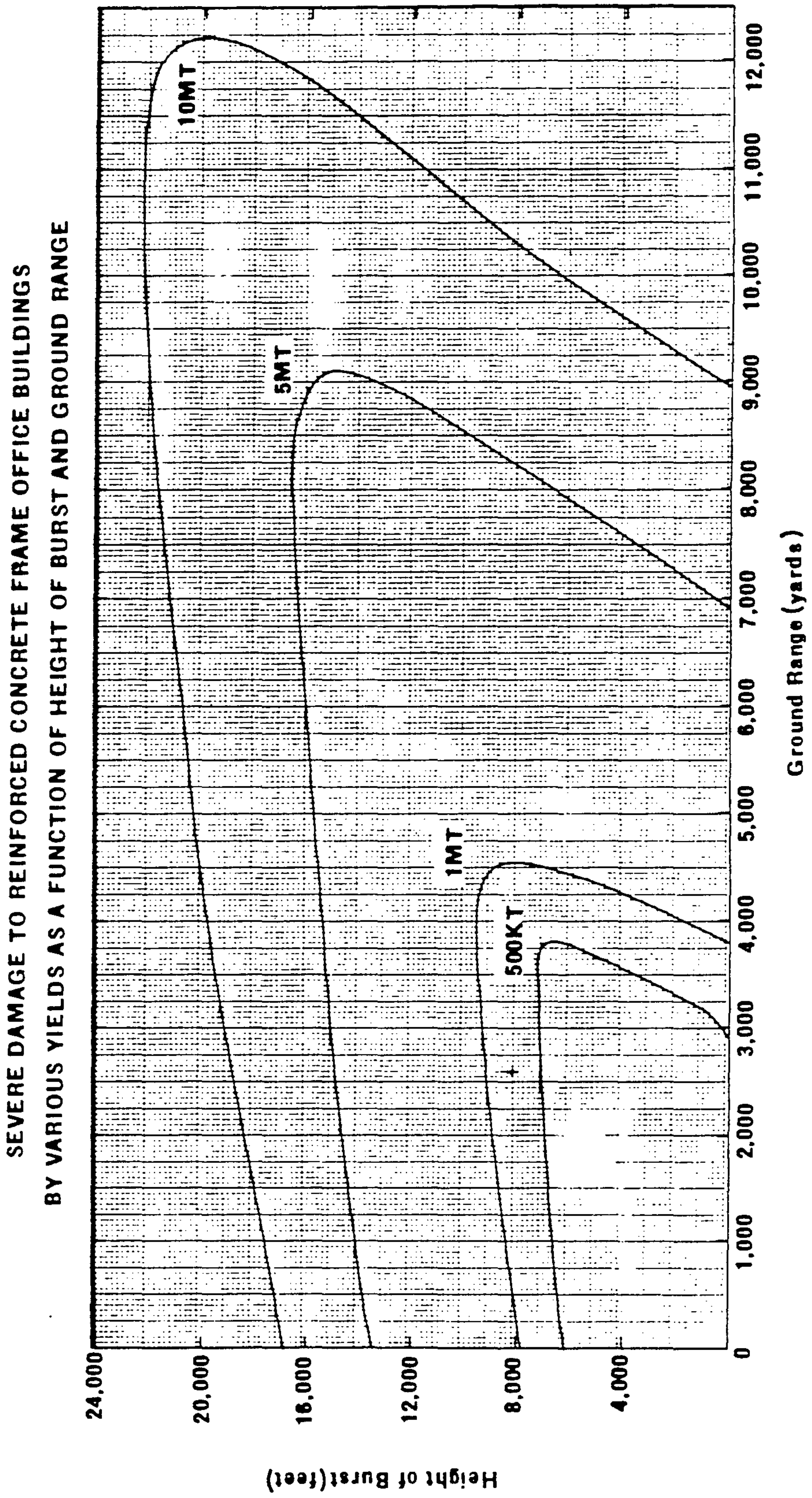


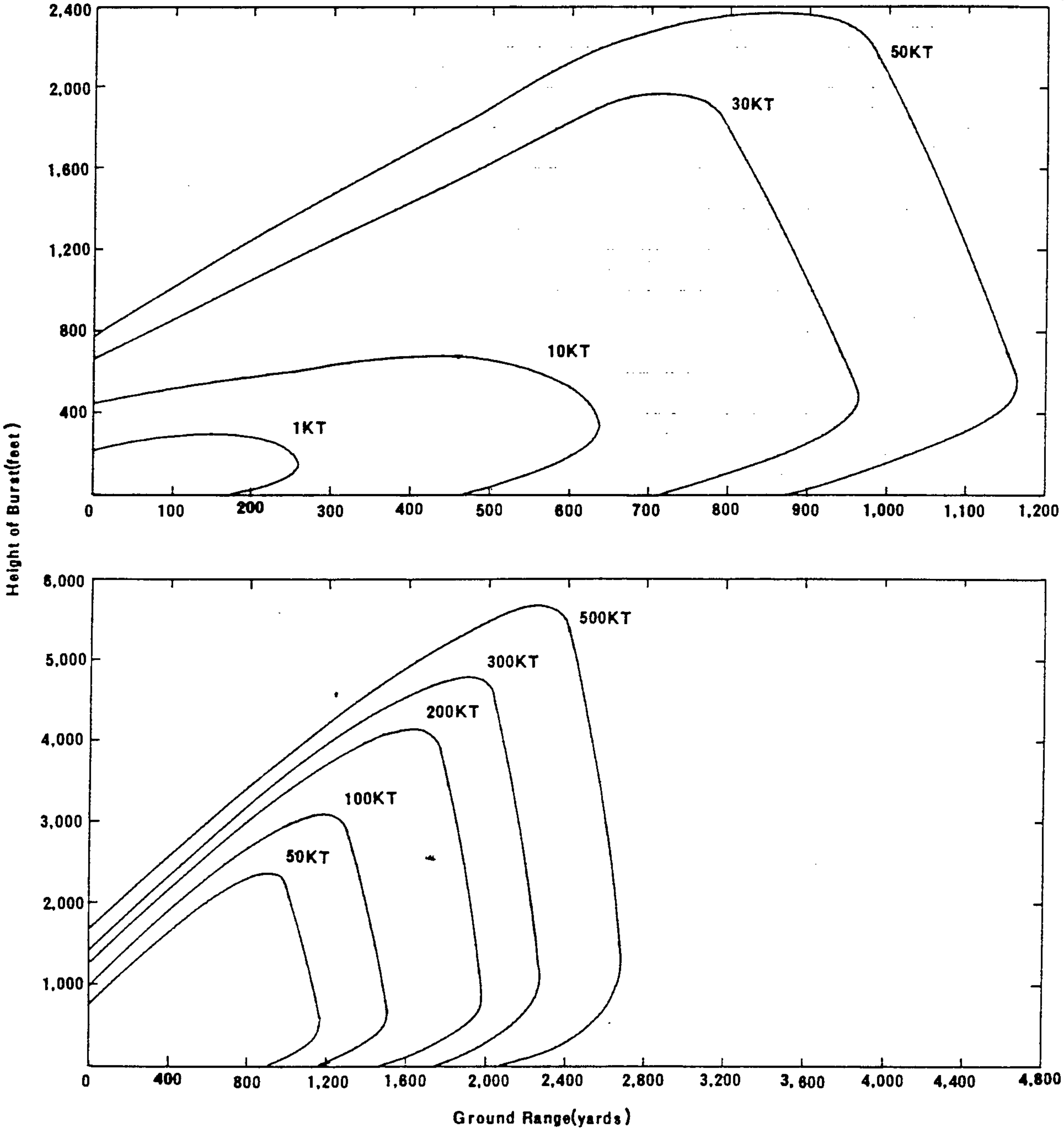
FIGURE 7-10C



SEVERE DAMAGE TO REINFORCED CONCRETE FRAME OFFICE BUILDINGS BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

FIGURE 7-11A
FIGURE 7-11B

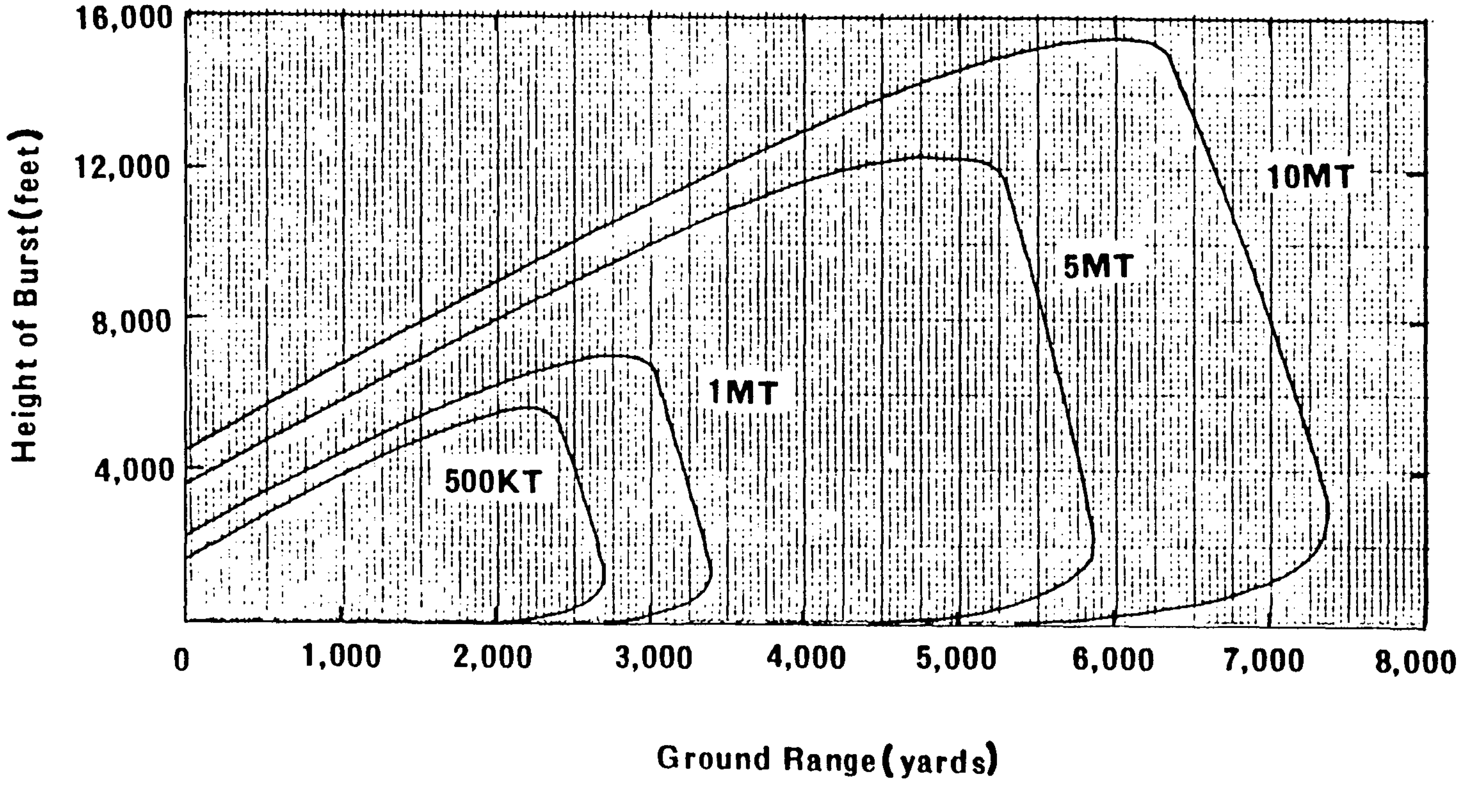
SEVERE DAMAGE TO HIGHWAY AND RAILWAY TRUSS BRIDGES OF 150 TO 250 FOOT SPAN
(BLAST NORMAL TO LONGITUDIONAL BRIDGE AXIS)
BY VARIOUS YIELDS AS FUNCTIONS OF HEIGHT OF BURST AND GROUND RANGE



~~CONFIDENTIAL~~

FIGURE 7-11C

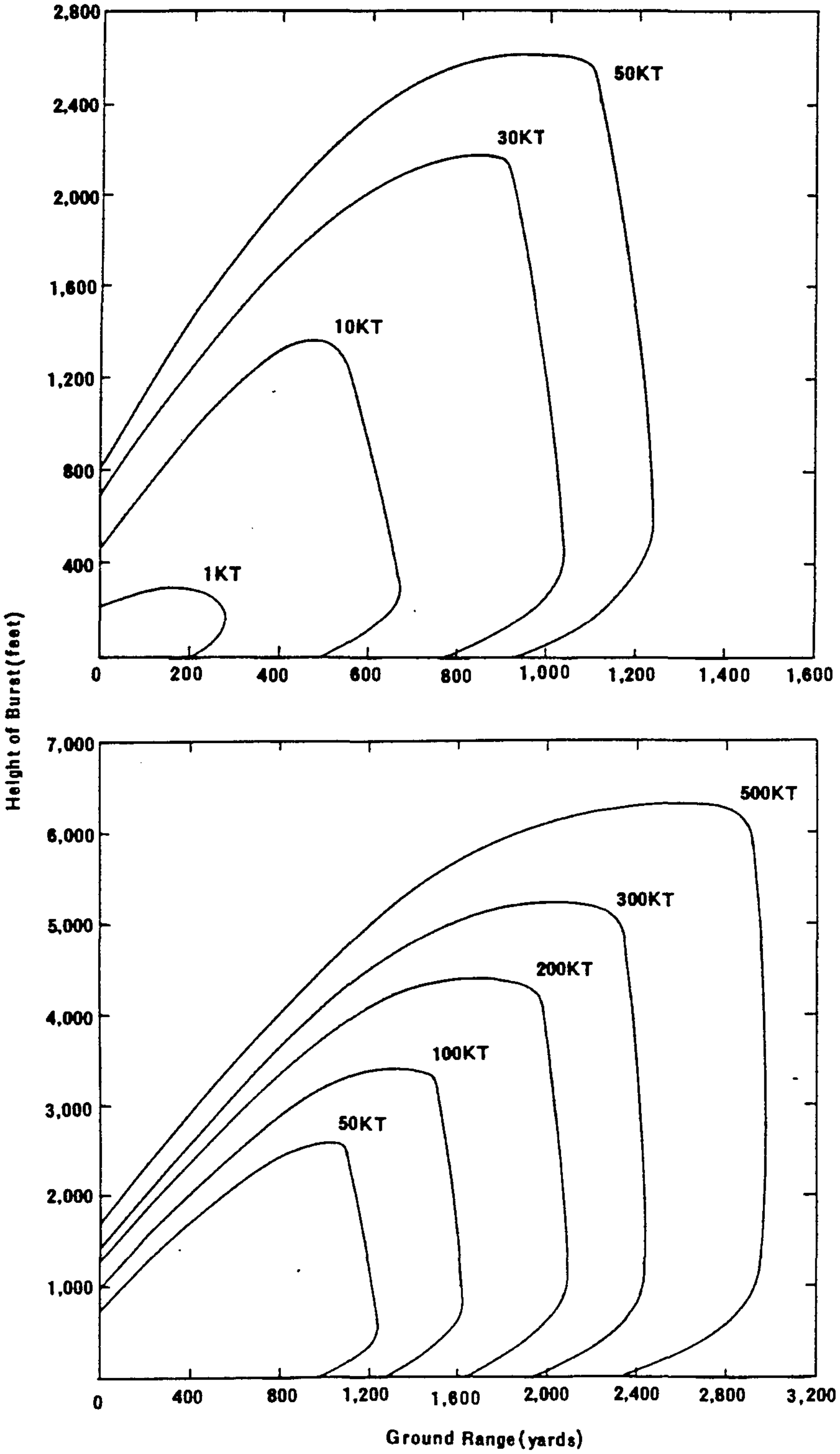
SEVERE DAMAGE TO HIGHWAY AND RAILWAY TRUSS BRIDGES OF 150 TO 250 FOOT SPAN
(BLAST NORMAL TO LONGITUDINAL BRIDGE AXIS)
BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



~~CONFIDENTIAL~~

FIGURE 7-12A
FIGURE 7-12B

SEVERE DAMAGE TO HIGHWAY AND RAILWAY TRUSS BRIDGES OF 250 TO 550 FOOT SPAN
(BLAST NORMAL TO LONGITUDINAL BRIDGE AXIS)
BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO HIGHWAY AND RAILWAY TRUSS BRIDGES OF 250 TO 550 FOOT SPAN
(BLAST NORMAL TO LONGITUDINAL BRIDGE AXIS)
BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

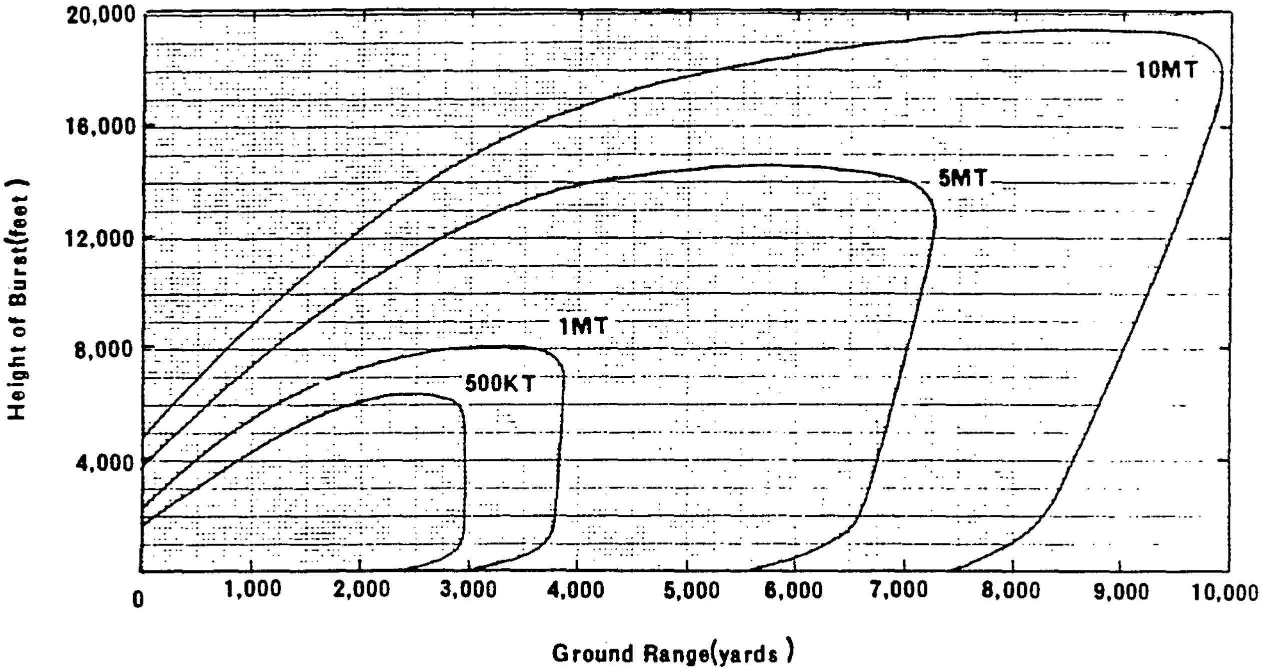


FIGURE 7-13A
FIGURE 7-13B

SEVERE DAMAGE TO M2 OR M4 FLOATING BRIDGES (RANDOM ORIENTATION) FOR VARIOUS YIELDS AS A FUNCTION OF GROUND RANGE AND HEIGHT OF BURST

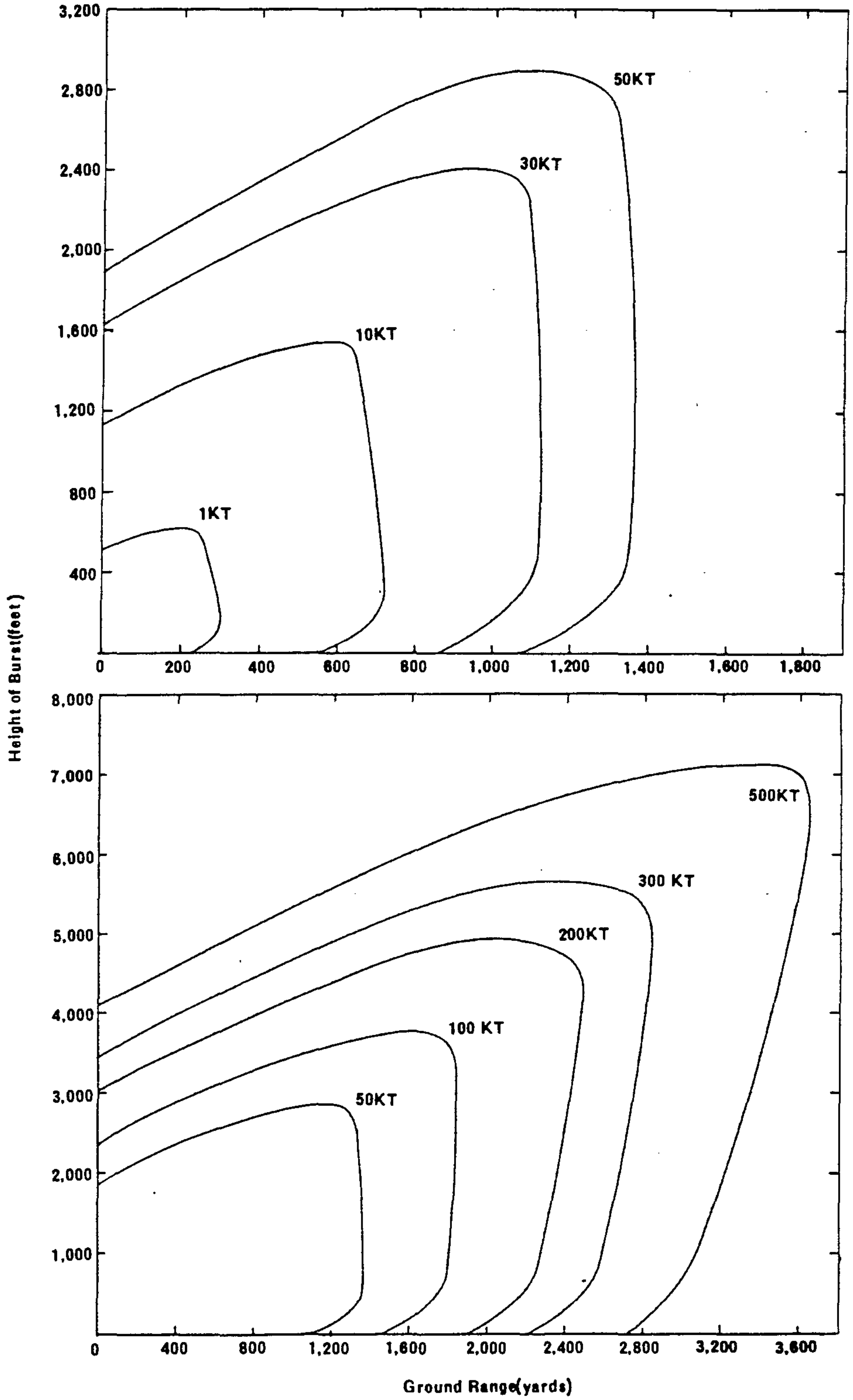


FIGURE 7-13C

SEVERE DAMAGE TO M2 OR M4 FLOATING BRIDGES (RANDOM ORIENTATION) FOR VARIOUS YIELDS AS A FUNCTION OF GROUND RANGE AND HEIGHT OF BURST

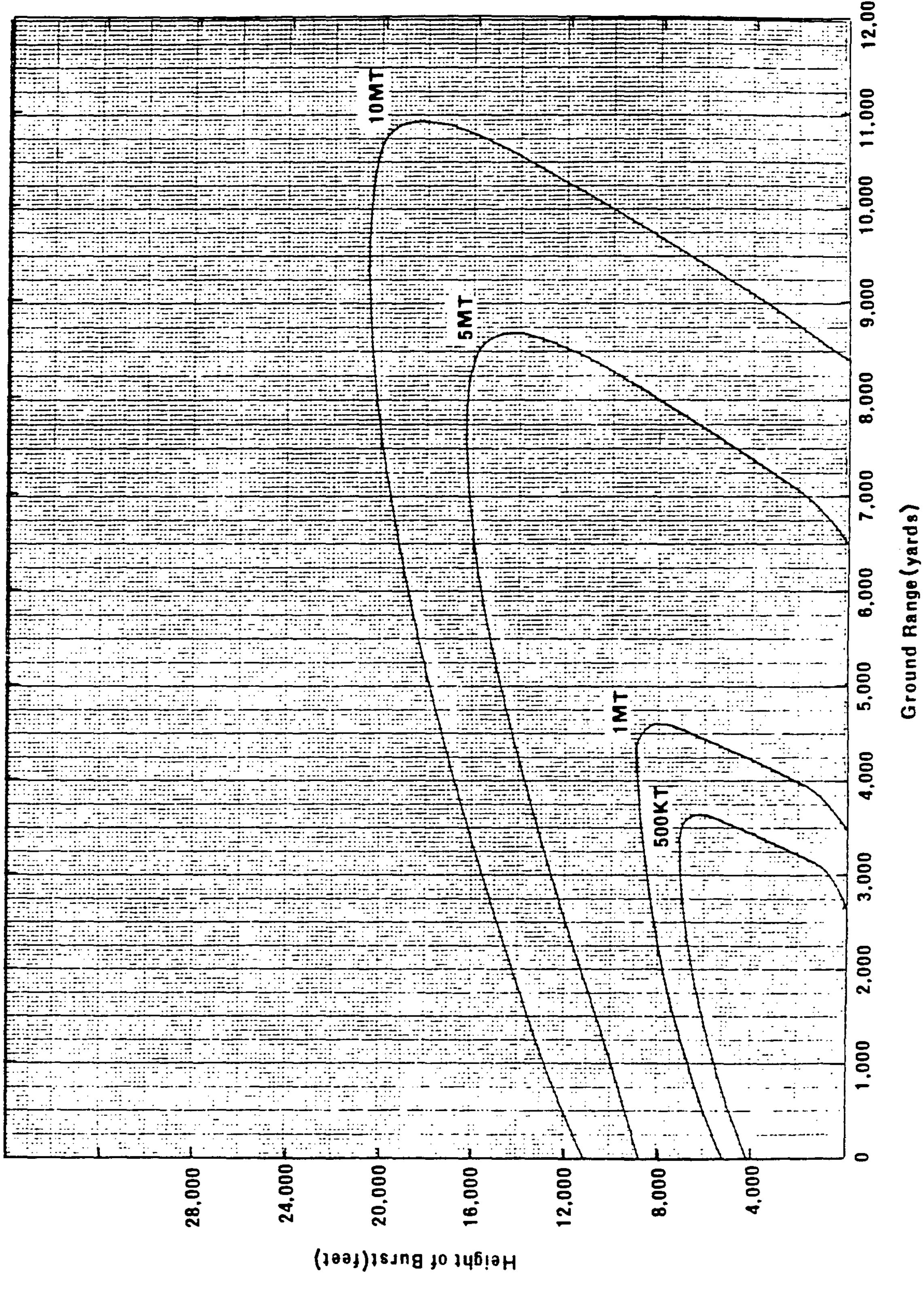
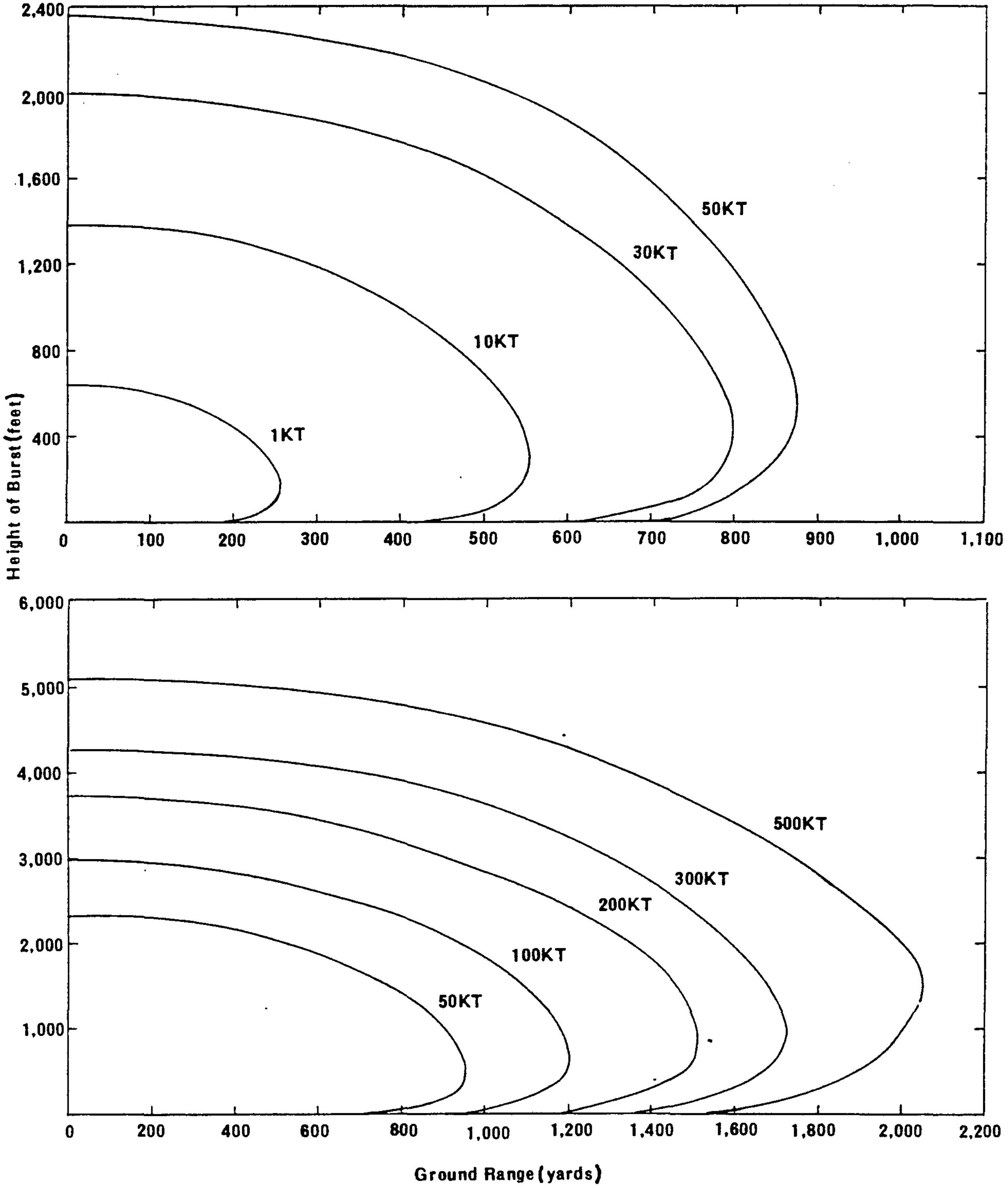
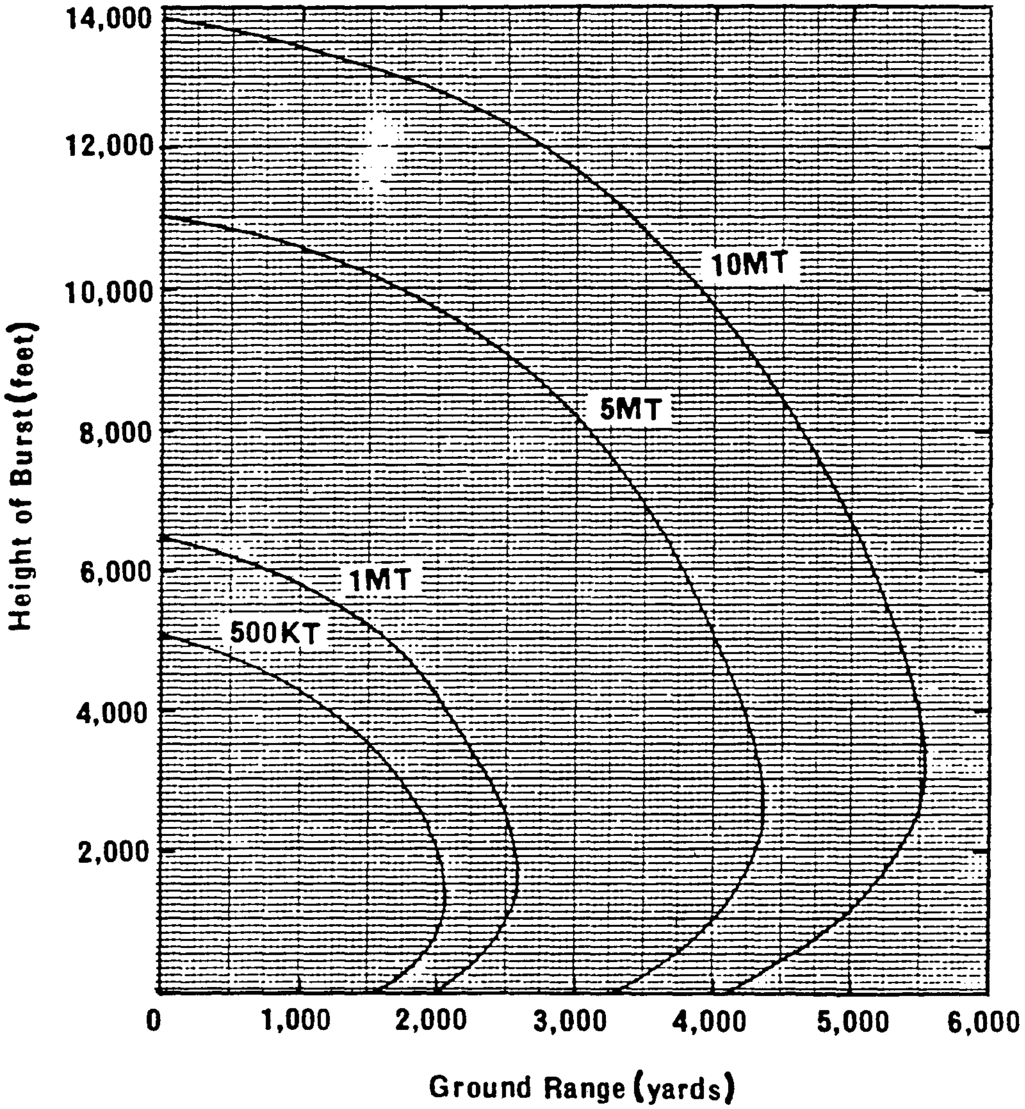


FIGURE 7-14A
FIGURE 7-14B

SEVERE DAMAGE TO EARTH COVERED LIGHT STEEL ARCH SHELTER
(10 GAUGE CORRUGATED STEEL WITH 20 TO 25 FOOT SPAN)
BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO EARTH COVERED LIGHT STEEL ARCH SHELTER (10 GAUGE CORRUGATED STEEL WITH 20 TO 25 FOOT SPAN) BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO EARTH COVERED LIGHT REINFORCED CONCRETE STRUCTURE BY VARIOUS YIELDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

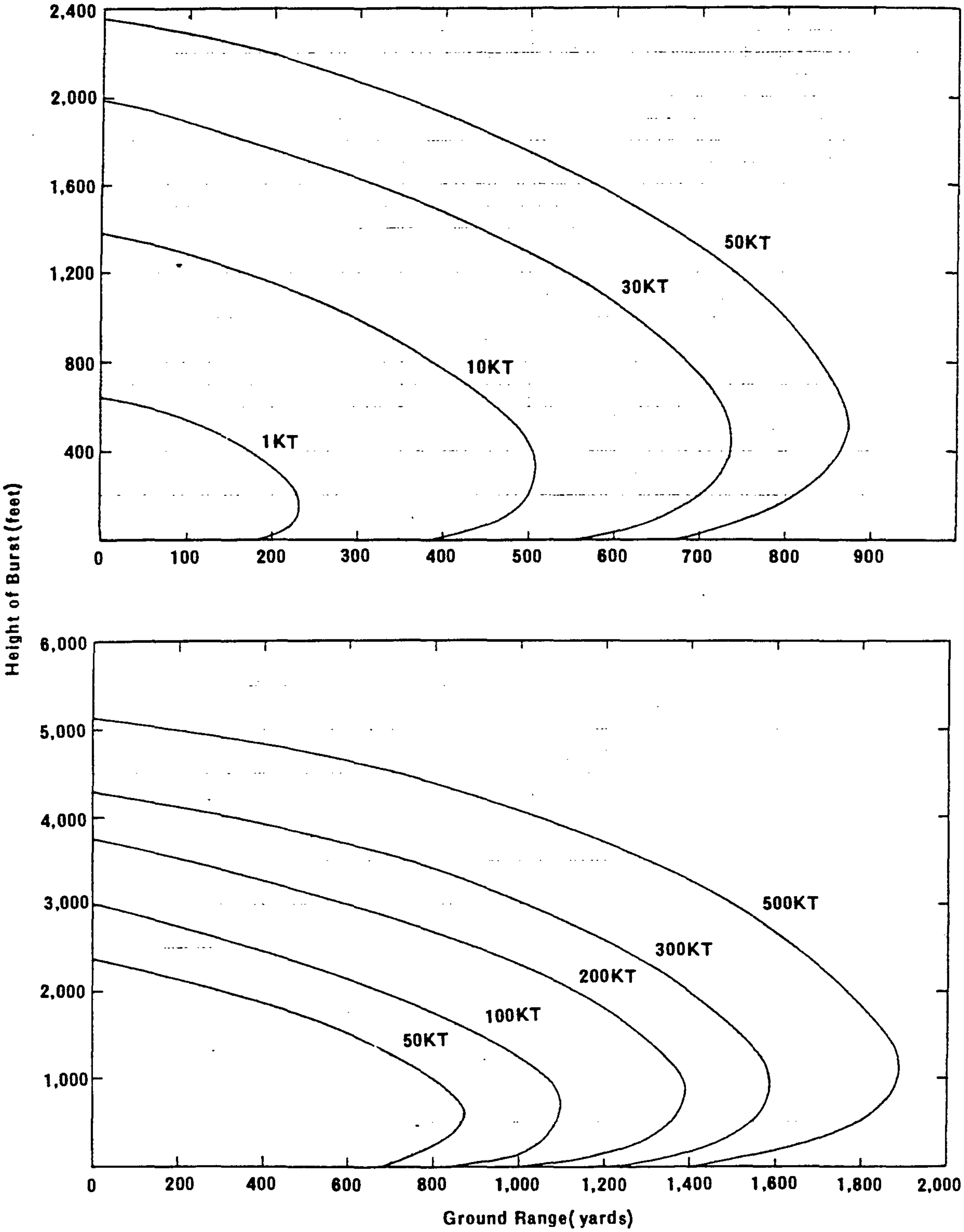
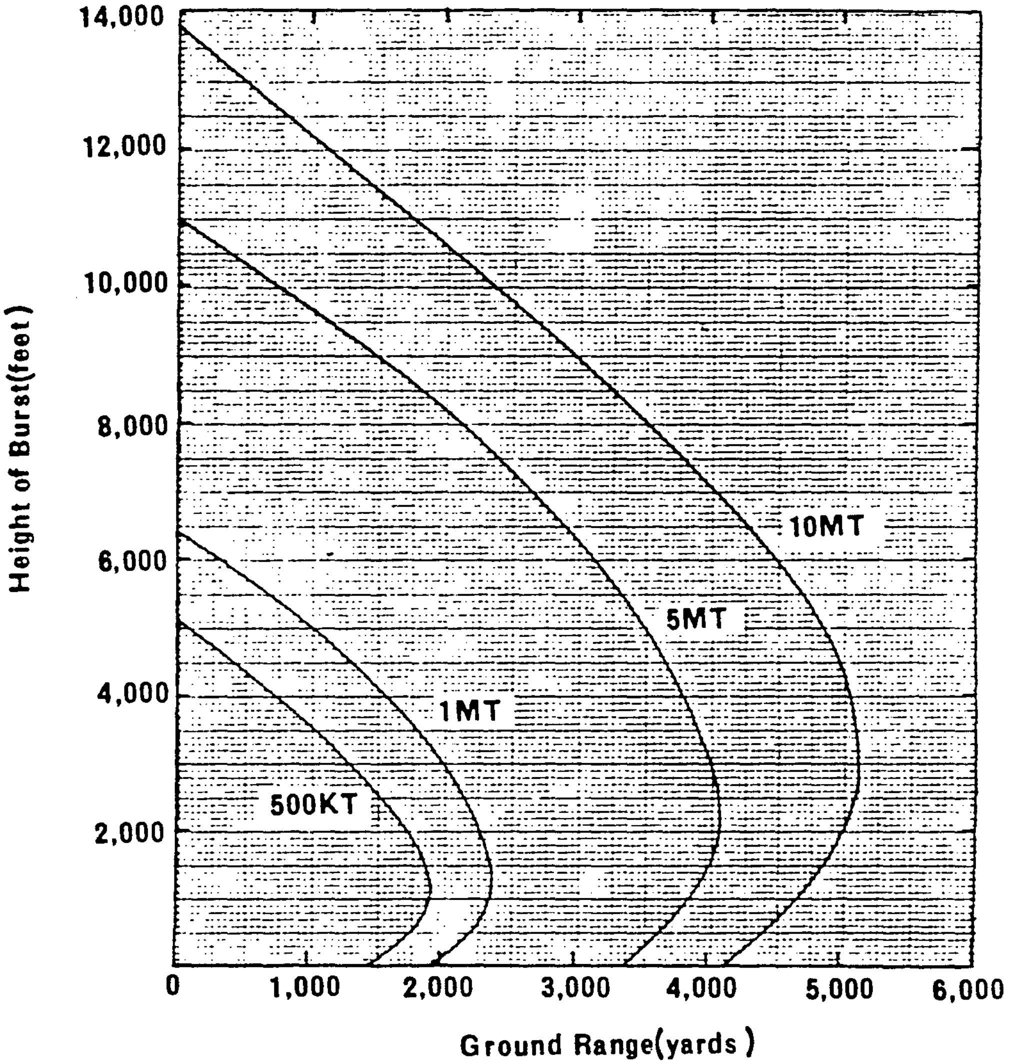


FIGURE 7-15C

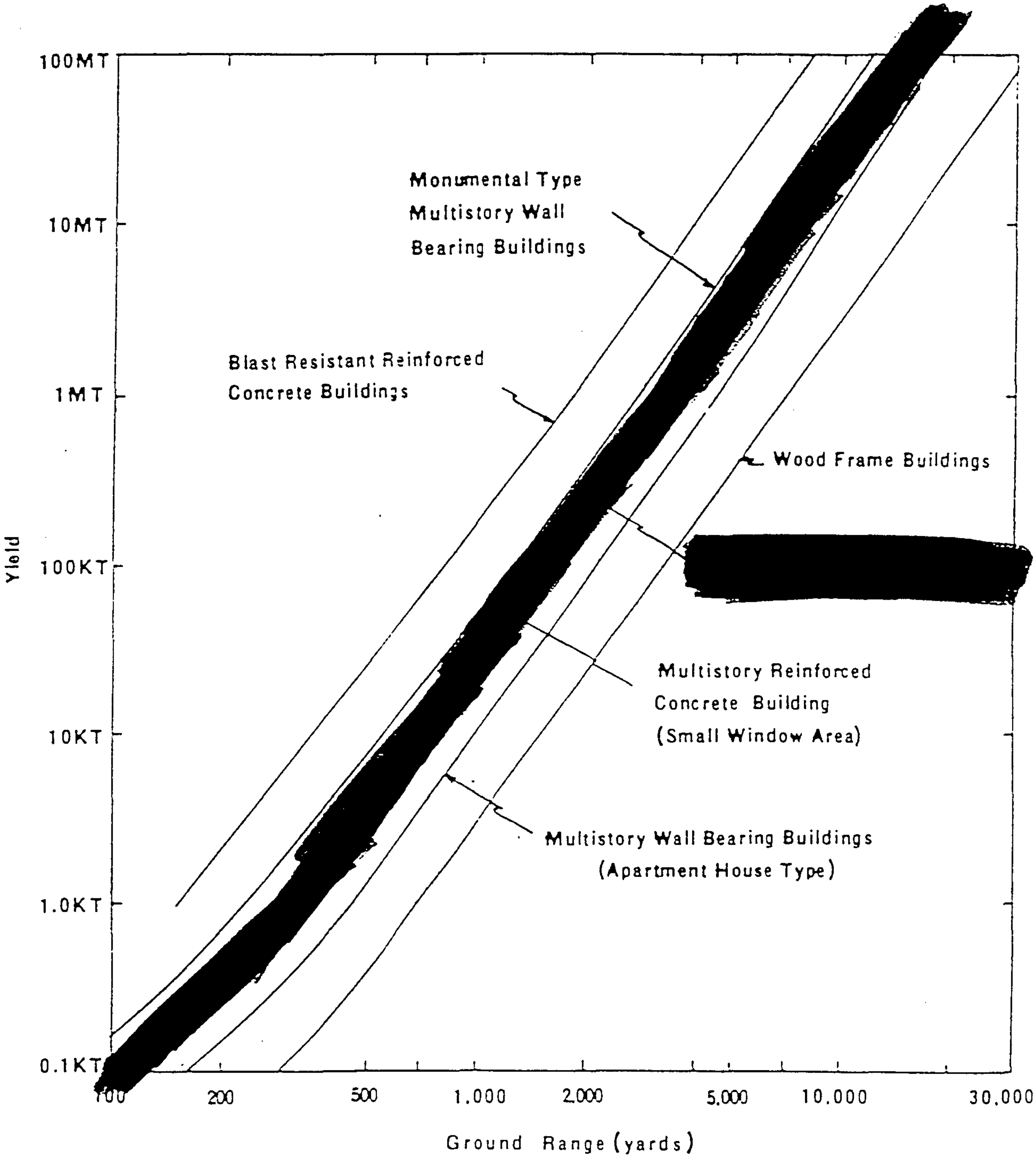
SEVERE DAMAGE TO EARTH COVERED LIGHT REINFORCED CONCRETE STRUCTURE BY VARIOUS YIELDS AS A FUNCTIONS OF HEIGHT OF BURST AND GROUND RANGE



[redacted]

FIGURE 7-16

SEVERE DAMAGE TO VARIOUS STRUCTURES PRIMARILY OVERPRESSURE-SENSITIVE BY SURFACE BURST OF VARIOUS YIELDS



[redacted]

[redacted]

ARMY
(b)(1)

[redacted]

FIGURE 7-17A

SEVERE DAMAGE TO VARIOUS STRUCTURES PRIMARILY DYNAMIC PRESSURE-SENSITIVE
BY SURFACE BURST OF VARIOUS YIELDS

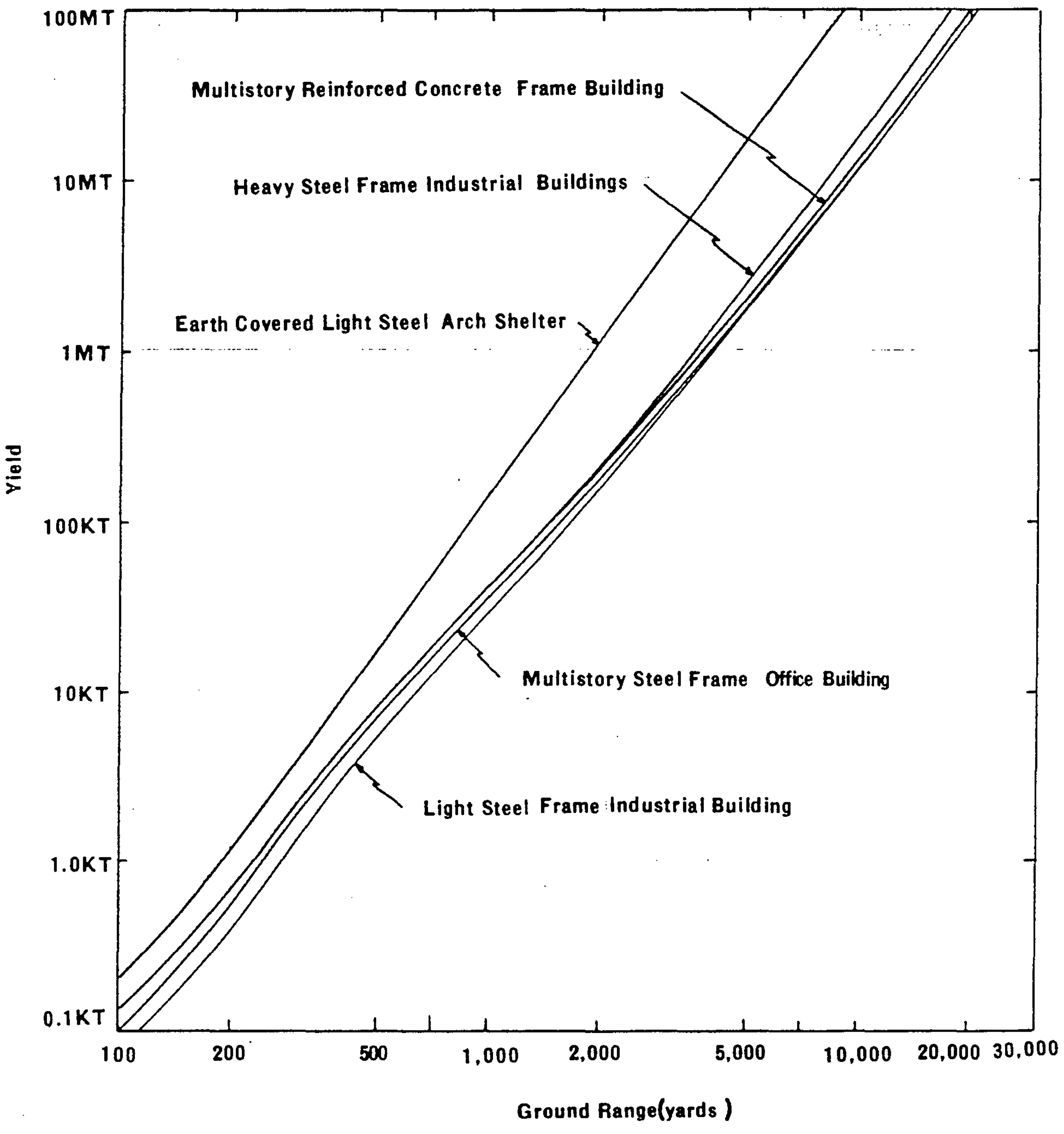
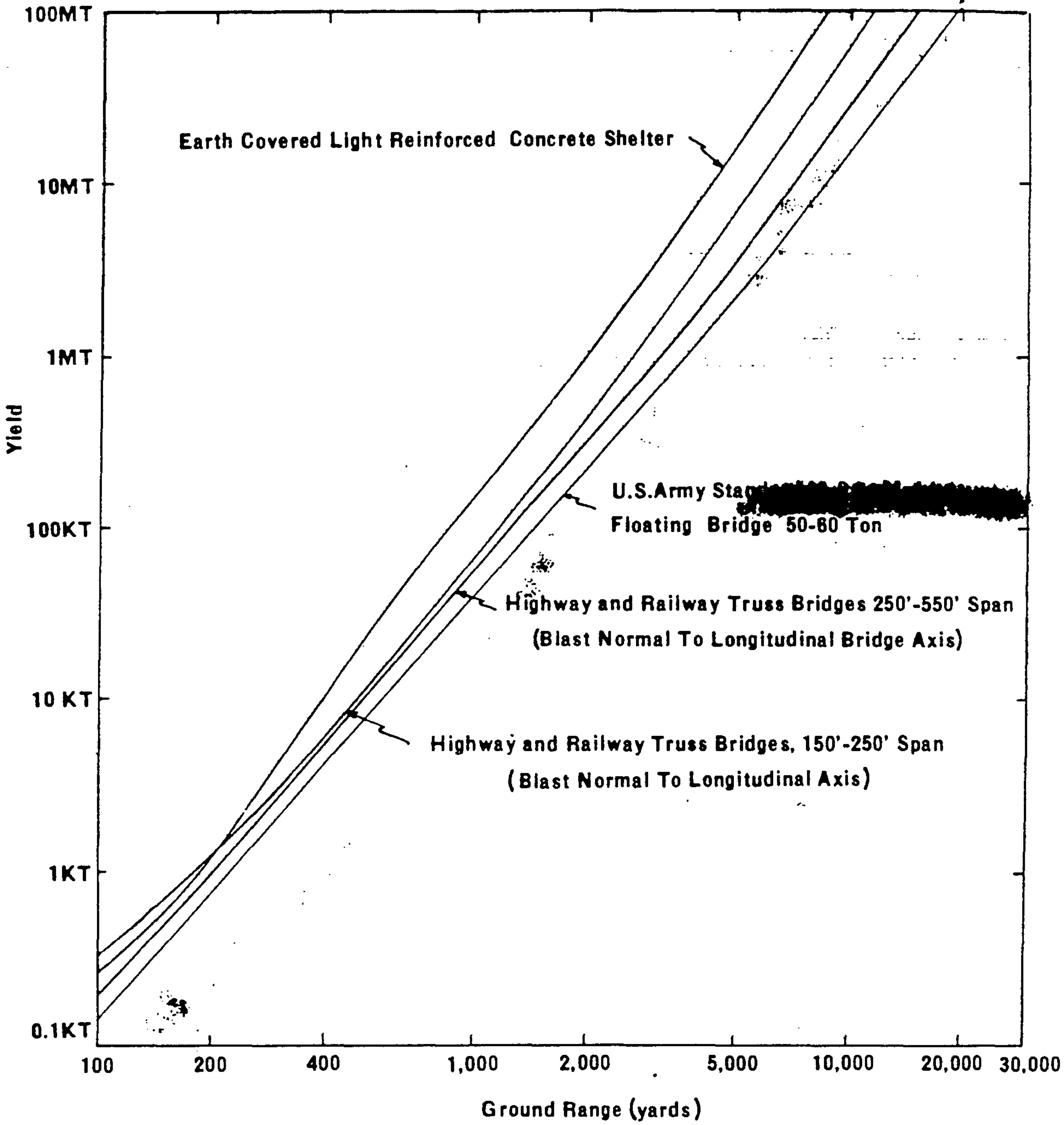
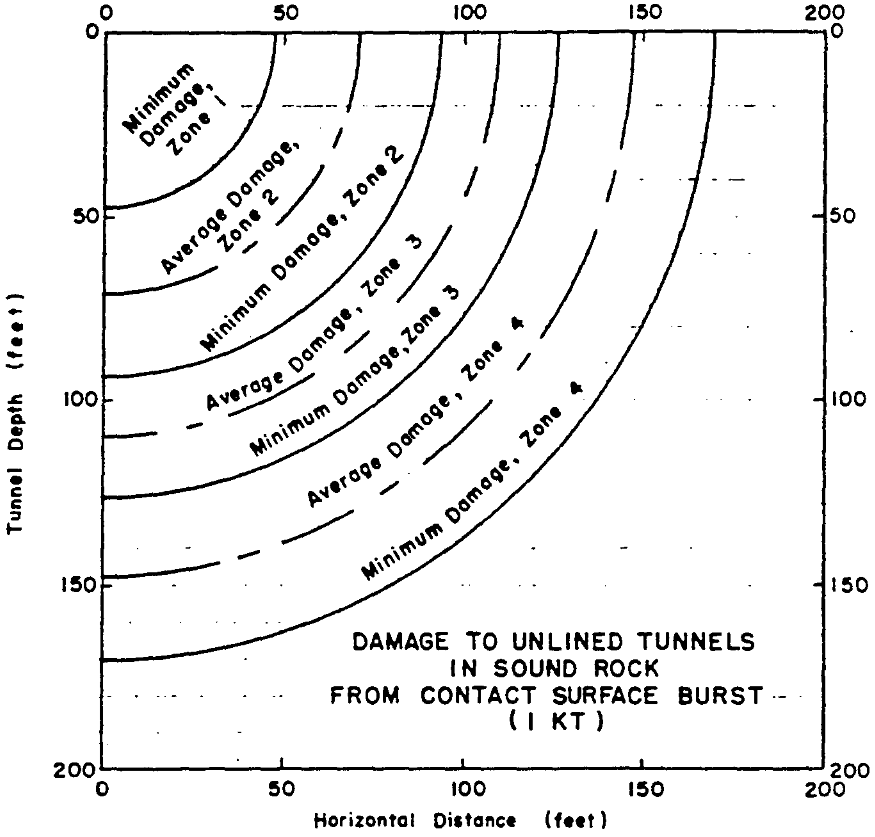


FIGURE 7-17B

SEVERE DAMAGE TO VARIOUS STRUCTURES PRIMARILY DYNAMIC PRESSURE-SENSITIVE BY SURFACE BURST OF VARIOUS YIELDS

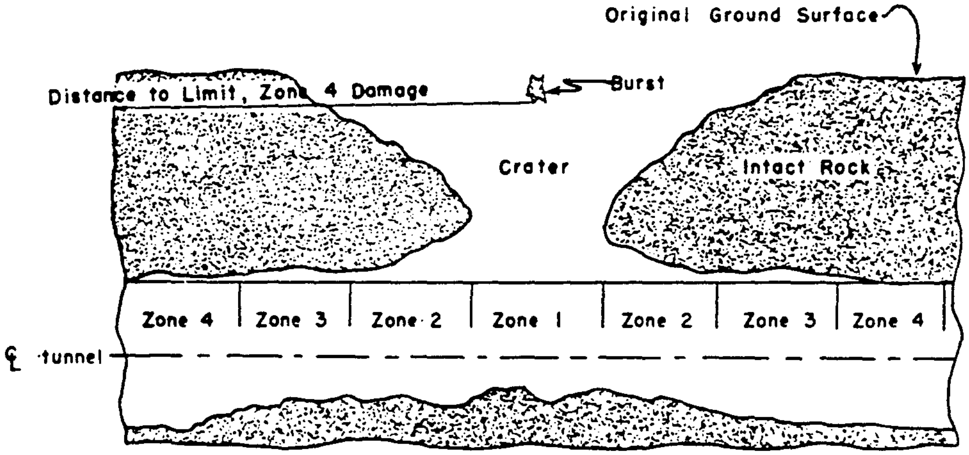




DAMAGE TO UNLINED TUNNELS IN SOUND ROCK FROM CONTACT SURFACE BURST (1 KT)

Zones of Damage to Unlined Tunnels in Sound Rock :

Zone 1. Crater opening into tunnel.
Zone 2. Increasing thickness of spalling.
Zone 3. Continuous spalling of about constant thickness.
Zone 4. Intermittent light spalling.



DAMAGE TO FIELD FORTIFICATIONS

Figures 7–20 through 7–22 are a series of plots of height of burst vs. scaled ground range for 50 percent probability of severe, moderate, or light damage to various field fortifications in Nevada type soil scaled to 1 KT. To determine 90 percent or 10 percent probability of damage to structures, lines of probability should be drawn between the indicated 50 percent probability lines. For example, because there is little difference between a line indicating approximately 10 percent probability of severe damage and one indicating 90 percent probability of moderate damage, a single line can represent both and should be drawn midway between the indicated lines for 50 percent probability of severe and moderate damage. To determine the range for 90 percent probability of severe damage use one-half the yield at the same burst height.

The curves in figure 7–22 are based on results of tests run in a *consolidated dry sand and gravel soil*. Trenches and foxholes in damp soil with stable vegetation or dry silty soil will receive moderate and severe damage at ranges less than those shown in figure 7–22. The curves of figure 7–22 are for average rectangular foxholes with the longitudinal axis perpendicular to the direction of air blast propagation. Damage will be equal or less for other orientations.

Scaling. To obtain heights of burst and distances for yields other than 1 KT, use the scaling procedure—

$$\frac{d_1}{d_2}=\frac{h_1}{h_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where d_1 and h_1 are ground distance and height of burst for yield W_1 KT, and d_2 and h_2 are the corresponding ground distance and height of burst for yield W_2 KT.

Example.

Given: A 50 KT burst at an altitude of 1,000 feet.

Find: To what horizontal distance there is a 50 percent probability of severe damage to an unrevetted foxhole in a dry, consolidated sand and gravel soil.

Solution:

$$h_1=\frac{h_2\times W_1^{1/3}}{W_2^{1/3}}=\frac{1{,}000\times 1}{(50)^{1/3}}=270 \text{ feet},$$

the corresponding burst height for 1 KT. From figure 7–22 the ground range for severe damage is 185 yards. To obtain the corresponding ground range for 50 KT:

$$d_2=\frac{d_1\times W_2^{1/3}}{W_1^{1/3}}=\frac{185\times(50)^{1/3}}{1}=680 \text{ yards.}$$

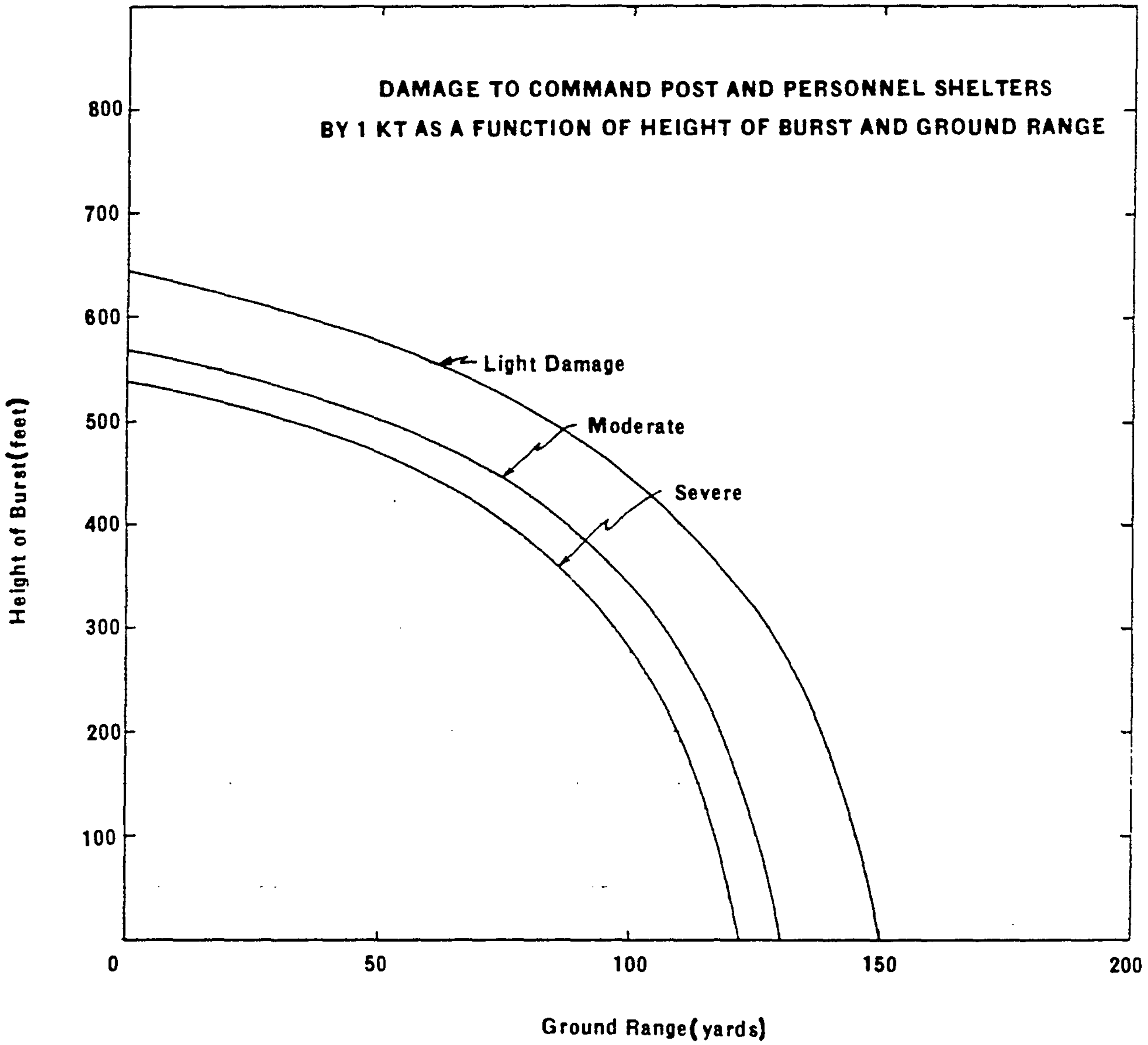
Answer.

Reliability. This figure is based on results of a limited number of full scale tests at which severe, moderate and light damage were observed.

Related material.

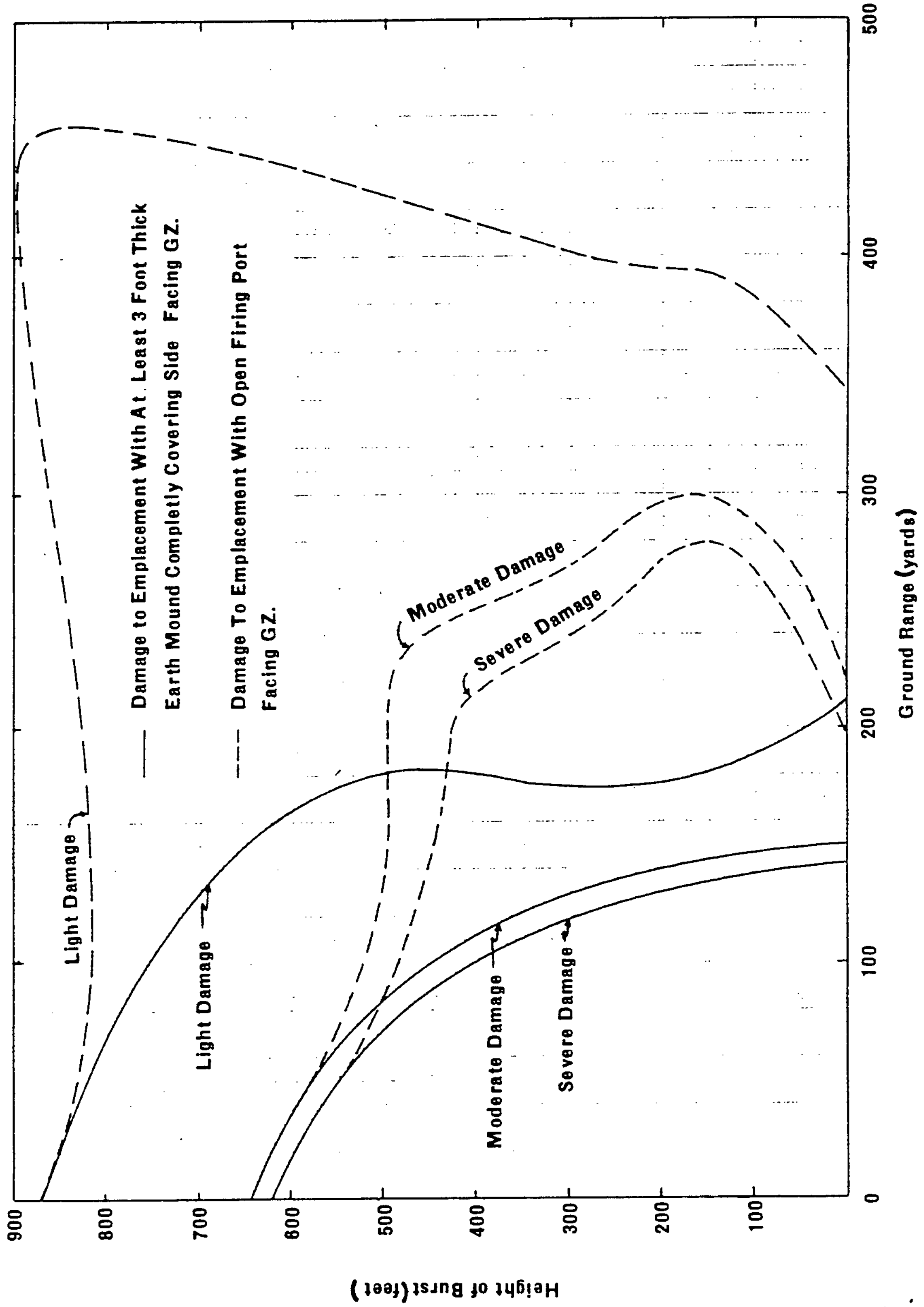
See paragraph 7.4.

FIGURE 7-20



DAMAGE TO COMMAND POST AND PERSONNEL SHELTERS BY 1 KT AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

DAMAGE TO MACHINE GUN EMPLACEMENTS
BY 1 KT AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



PAGE 7-55 WITHHELD IN
ITS ENTIRETY

b. Air Blast Damage. As the depth of a burst is decreased, a transition from water shock to air blast as the primary damage-producing mechanism occurs. Peak overpressure is considered a satisfactory parameter for estimating damage to ships from air blast. Peak overpressures of 5 psi cause light damage to most types of surface ships, while overpressures required for severe damage vary from 25 psi for destroyers to 45 psi for battleships. Figures 8–1 and 8–2 present damage ranges for a 1 KT detonation for heights of burst less than 600 feet and depths of burst less than 800 feet, with means of scaling to other yields. A tabulation of peak overpressure required to cause ship damage is given in table 8–1 for use with burst heights greater than those shown in figures 8–1 and 8–2. For such burst heights, distances to which overpressures extend can be obtained from figure 2–17.

Table 8–1. Surface Ship Peak Air Overpressure Damage Criteria

Type of ship	Peak air overpressure (psi)		
	Severe	Moderate	Light
Aircraft carriers	30	20	5
Battleships	45	25	5
Cruisers (heavy)	40	20	5
Cruisers (light) (AA)	30	20	5
Destroyers	25	15	5
Pontoons (for pier construction)	60	------	------
Transports	30	20	5
LST's, landing craft and landing vehicles	25	15	5
Submarines (surfaced)	80	60	------

c. Water Wave Damage. Water waves are a contributing factor in causing damage to surface ships. Wave action may add to the damage to a ship which has already been weakened by air and water shock. The waves may also cause "hogging" damage to ships oriented end-on to the burst, and may cause ships oriented beam-on to the burst to capsize. Small craft may be overturned and sunk or destroyed by wave action.

d. Thermal Damage. Thermal damage to naval vessels and topside equipment is probably limited to superficial scorching of exposed organic surfaces (including paint). Fires are unlikely to originate aboard vessels as the result of thermal radiation from a nuclear explosion, except in cases where severe and probably overriding damage due to blast is also sustained.

8.3 Subsurface Target Damage

a. Submarines.

(1) *Air blast damage.* Air blast damage to surfaced submarines is significant only for the case of surface, transition zone or air bursts. Peak air overpressures of 80 and 60 psi are expected to cause severe and moderate damage, respectively, to surfaced submarines.

(2) *Water shock damage.* Water shock is the controlling damage-producing mechanism for a submerged submarine for any burst position, and also for a surfaced submarine subjected to an underwater burst. The criterion used for estimating lethal hull damage is a function of "excess impulse." This excess impulse is defined as the impulse delivered by that portion of the shock overpressure which is in excess of the static collapse pressure minus the hydrostatic pressure. In deep water when a sharp change in water temperature with depth exists (thermocline) and the weapon is fired in close proximity to this region, refraction may reduce the range for a given degree of damage on the order of perhaps 20 percent. This reduction will only occur when the weapon and the submarine are on opposite sides of the thermocline. For weapons fired well below or above the thermocline, there should be no reduction. Isodamage curves for the hull lethal range and interior shock damage range are presented in figures 8–4 and 8–5 for a submarine with a 600 psi static collapse pressure subjected to a 10 KT and a 30 KT surface or underwater detonation, with methods for scaling to other yields. No account of refraction has been taken in the damage curves presented. Non-linear effects as described in paragraph 2.3 have been incorporated. Initial translational

velocity is the criterion used for prediction of shock damage to submarine equipment.

b. Underwater Mines. Underwater mines are expected to be neutralized when the peak pressure acting on the mines is equal to or greater than the mine case static collapse pressure, or when the mines are within the crater. Figures 8–6 through 8–8 show the neutralization ranges for mines with hydrostatic collapse pressures of 250, 500, and 1,000 psi in depths of water of 50, 100, and 200 feet and for a range of yields from 1 to 100 KT. These curves are computed for mines and burst both on the bottom.

SURFACE SHIP DAMAGE

Figure 8-1 gives estimated ranges for severe damage (probable sinking) plotted as a function of burst height and depth for surface ships for a 1 KT detonation. Figure 8-2 gives the ranges for moderate (immobilization) damage and for light damage as functions of burst height and shallow depths. Figure 8-3 is an extended plot of light damage vs. depth of burst. This latter figure enables an estimate to be made for the effect of the bottom reflection pressures on the predicted light damage range using the assumptions given in paragraph 8.2*a* (i. e., a flat perfect reflector bottom and a burst depth at the image of the actual burst point). For evaluation of light damage, a value should be found for both the direct shock wave and the bottom reflected shock wave and the larger value chosen.

Scaling. For yields other than 1 KT the following relations can be used to estimate ranges for a given degree of damage:

$$\frac{d_1}{d_2}=\frac{W_1'^{1/3}}{W_2'^{1/3}}=\frac{h_1}{h_2},$$

where d_1=range for a given degree of damage for yield W'_1 KT at a depth h_1, and d_2=range for a given degree of damage for yield W'_2 KT at depth h_2.

Example.

Given: A 30 KT burst at a depth of 2,000 feet in 5,000 feet of water.

Find:

(*a*) The range at which an aircraft carrier suffers severe damage.

(*b*) The range at which a destroyer suffers light damage.

Solution:

(*a*) The depth of 2,000 feet for a 30 KT burst corresponds for a 1 KT to

$$\frac{h_1}{h_2}=\frac{W_1'^{1/3}}{W_2'^{1/3}} \text{ or } h_1=\frac{h_2\times(W_1'^{1/3})}{W_2'^{1/3}}$$

$$h_1=\frac{2{,}000(1)}{(W'_2)^{1/3}}=\frac{2{,}000}{(30)^{1/3}}=640 \text{ feet.}$$

From figure 8-1 the range at which an aircraft carrier suffers severe damage from a 1 KT burst 640 feet below the surface is 320 yards.

The range of severe damage to an aircraft carrier for a 30 KT detonation at a depth of 2,000 feet is then

$$\frac{d_1}{d_2}=\frac{W_1'^{1/3}}{W_2'^{1/3}} \text{ or } d_2=\frac{(d_1)\times(W'_2)^{1/3}}{W_1'^{1/3}}=$$

$$\frac{(320)\times(30)^{1/3}}{1}=1{,}000 \text{ yards.}$$ *Answer.*

(*b*) From either figure 8-2 or 8-3 the range at which a destroyer suffers light damage from the direct shock wave of a 1 KT burst at 640 feet below the surface is 990 yards.

The imaginary burst point from which the bottom reflected shock waves are assumed to come is equal to the depth of the water plus the height of the weapon above the bottom, or 5,000+3,000=8,000 feet for the 30 KT weapon. The corresponding depth for a 1 KT is

$$\frac{h_1}{h_2}=\frac{W_1'^{1/3}}{W_2'^{1/3}} \text{ or } h_1=\frac{h_2\times W_1'^{1/3}}{W_2'^{1/3}},$$

$$h_1=\frac{8{,}000\times(1)}{(W'_2)^{1/3}}=\frac{8{,}000}{(30)^{1/3}}=2{,}560 \text{ ft.}$$

From figure 8-3 the range at which a destroyer suffers light damage from the shock wave of a 1 KT burst at 2,560 feet is 1,300 yards. Since this is greater than the range noted above (990 yards), the bottom reflected shock wave governs. Hence the range of light damage to a destroyer from a 30 KT burst at a depth of 2,000 feet in 5,000 feet of water is then,

$$\frac{d_1}{d_2}=\frac{W_1'^{1/3}}{W_2'^{1/3}} \text{ or } d_2=\frac{(d_1)\times(W'_2)^{1/3}}{W_1'^{1/3}}=$$

$$\frac{(1{,}300)\times(30)^{1/3}}{1}=4{,}000 \text{ yards.}$$ *Answer.*

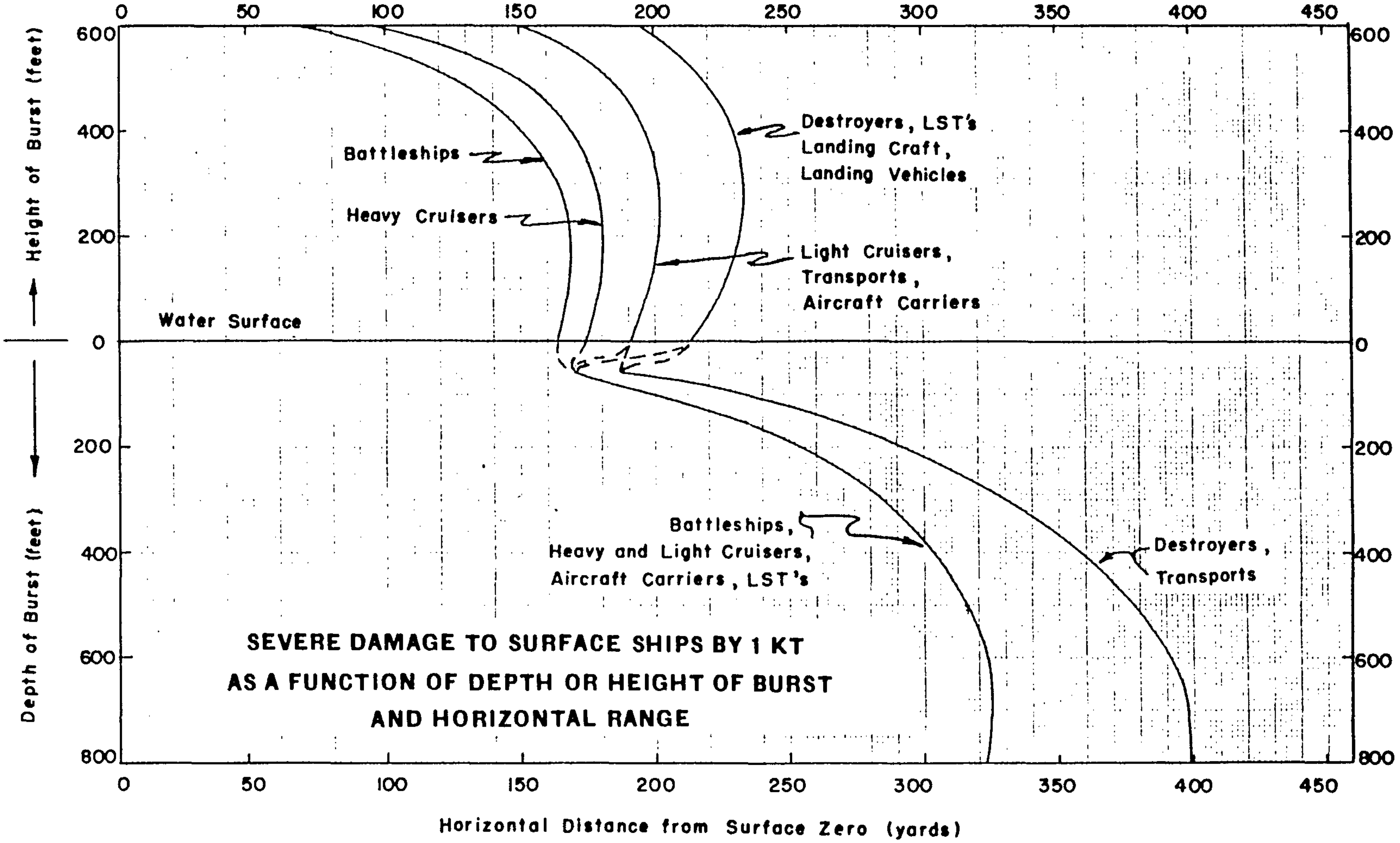
Reliability. Based on limited data. Predictions become less reliable as depth of burst decreases.

Related Material.

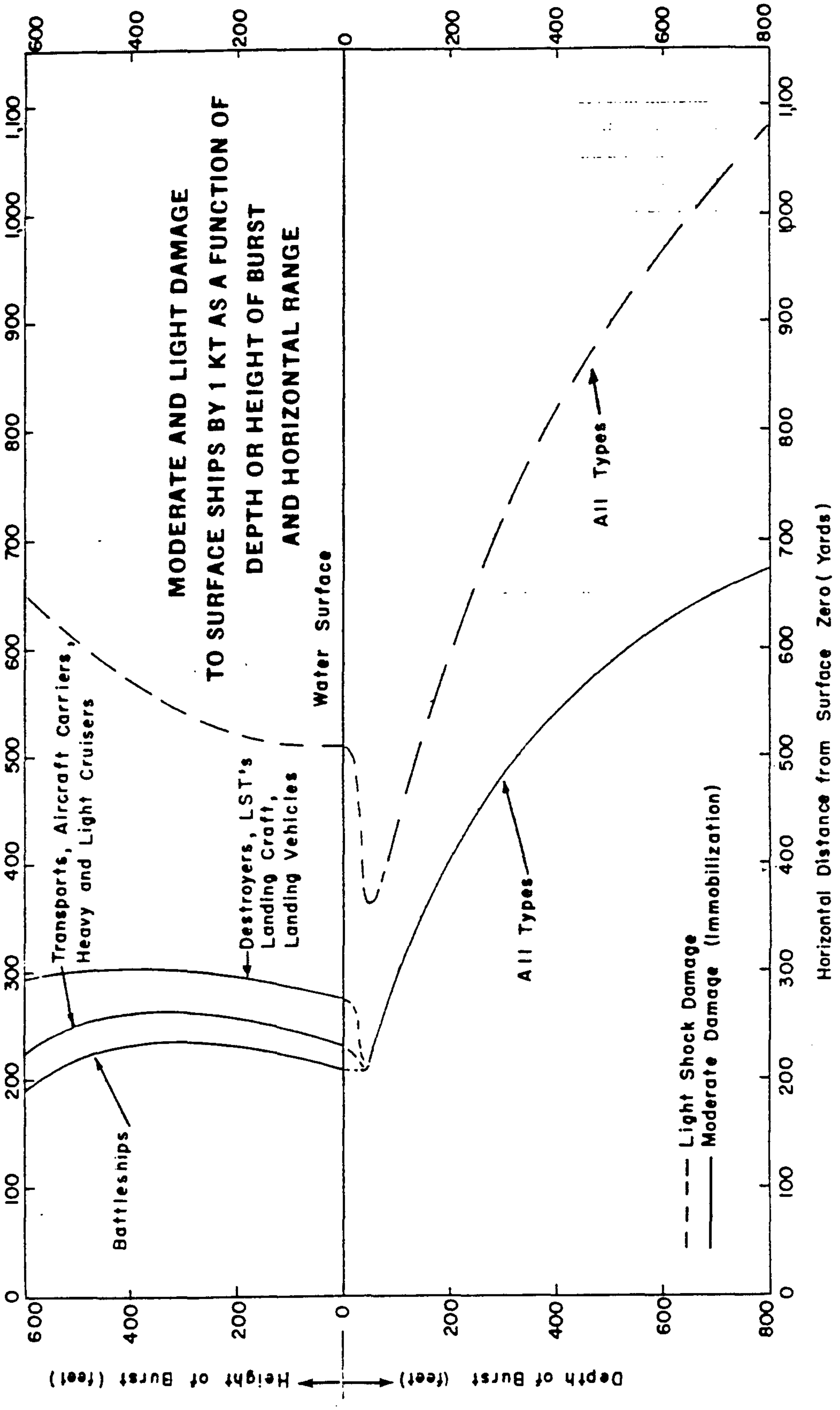
See paragraphs 8.1 and 8.2.

See also figures 8-4 and 8-5 for submarine damage.

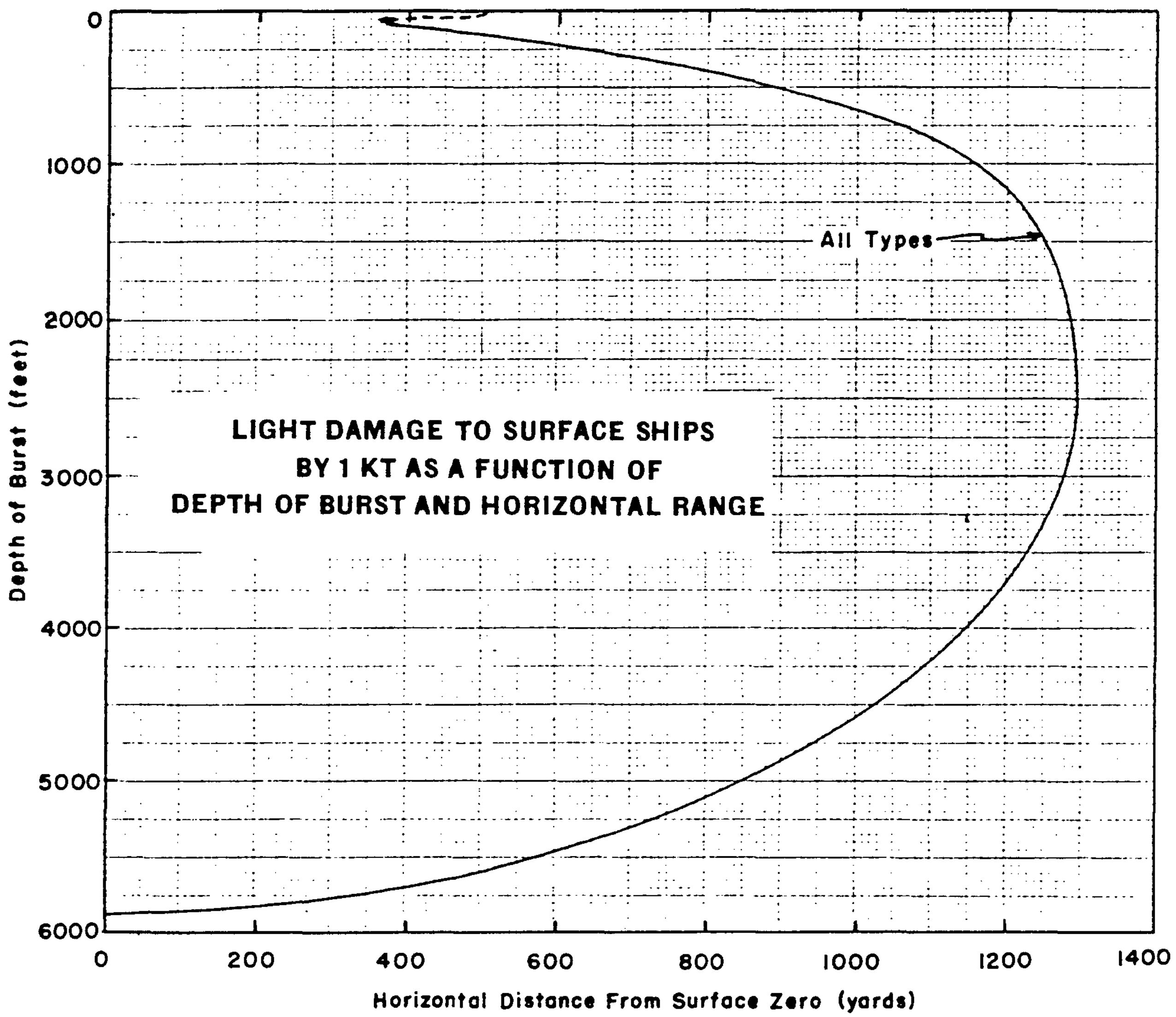
FIGURE 8-1



SEVERE DAMAGE TO SURFACE SHIPS BY 1 KT
AS A FUNCTION OF DEPTH OR HEIGHT OF BURST
AND HORIZONTAL RANGE



MODERATE AND LIGHT DAMAGE TO SURFACE SHIPS BY 1 KT AS A FUNCTION OF DEPTH OR HEIGHT OF BURST AND HORIZONTAL RANGE



LIGHT DAMAGE TO SURFACE SHIPS BY 1 KT AS A FUNCTION OF DEPTH OF BURST AND HORIZONTAL RANGE

SUBMARINE DAMAGE

Figure 8-4 presents isodamage curves of lethal hull range for a submarine with a static collapse pressure of 600 psi when subjected to a 10 KT or a 30 KT burst. For submarines of other structural strengths, the lethal range is assumed to be inversely proportional to the pressure hull thickness. For depths of submergence between those presented in the curves a linear interpolation may be used. Figure 8-5 presents isodamage curves for interior shock damage. While the ranges given in figure 8-4 are dependent upon hull strength, those in figure 8-5 are independent of hull strength. For shallow submarine submergence the range for interior shock damage is greater than the lethal hull range. However, for a depth of submergence greater than about 350 feet the lethal hull range predominates.

Scaling. Although direct scaling techniques are not applicable, useful data with sufficient accuracy may be obtained by these approximate procedures.

(1) For yields in the range of 30 to 100 KT, a given depth of burst and a given submarine depth, the following relation can be used with the 30 KT curves to estimate ranges for a given degree of damage:

$$\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where d_1=range for a given degree of damage for a yield of W_1 KT, and d_2= range for a given degree of damage for a yield of W_2 KT.

(2) A similar relation should be used for yields in the range of 3 to 10 KT using the 10 KT curves. For yields between 10 and 30 KT, compute a range using the 10 KT curves as the basis for cube root scaling and a second range using the 30 KT curves as the basis for cube root scaling, then linearly interpolate between these two computed ranges.

Example.

Given: A 20 KT weapon burst at a depth of 400 feet.

Find: The lethal hull range for a submarine (600 psi static collapse pressure) submerged to a depth of 100 feet.

Solution: From figure 8-4, the lethal hull range for a 10 KT burst at 400 feet is 1,040 yards. The scaled range is then,

$$\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}} \text{ or } d_2=\frac{W_2^{1/3}\times d_1}{W_1^{1/3}},$$

$$d_2=\frac{(20)^{1/3}}{(10)^{1/3}}\times 1{,}040=1{,}300 \text{ yards.}$$

The lethal range for a 30 KT bomb burst at 400 feet is 1,300 yards. The scaled range is then,

$$d_2=\frac{W_2^{1/3}\times d_1}{W_1^{1/3}}$$

or

$$d_2=\frac{(20)^{1/3}}{(30)^{1/3}}\times 1{,}300=1{,}100 \text{ yards.}$$

The lethal hull range for a 20 KT bomb burst at a depth of 400 feet is then $d_2=1{,}300-\frac{1}{2}(1{,}300-1{,}100)=1{,}200$ yards. *Answer.*

Reliability. Based on limited data.

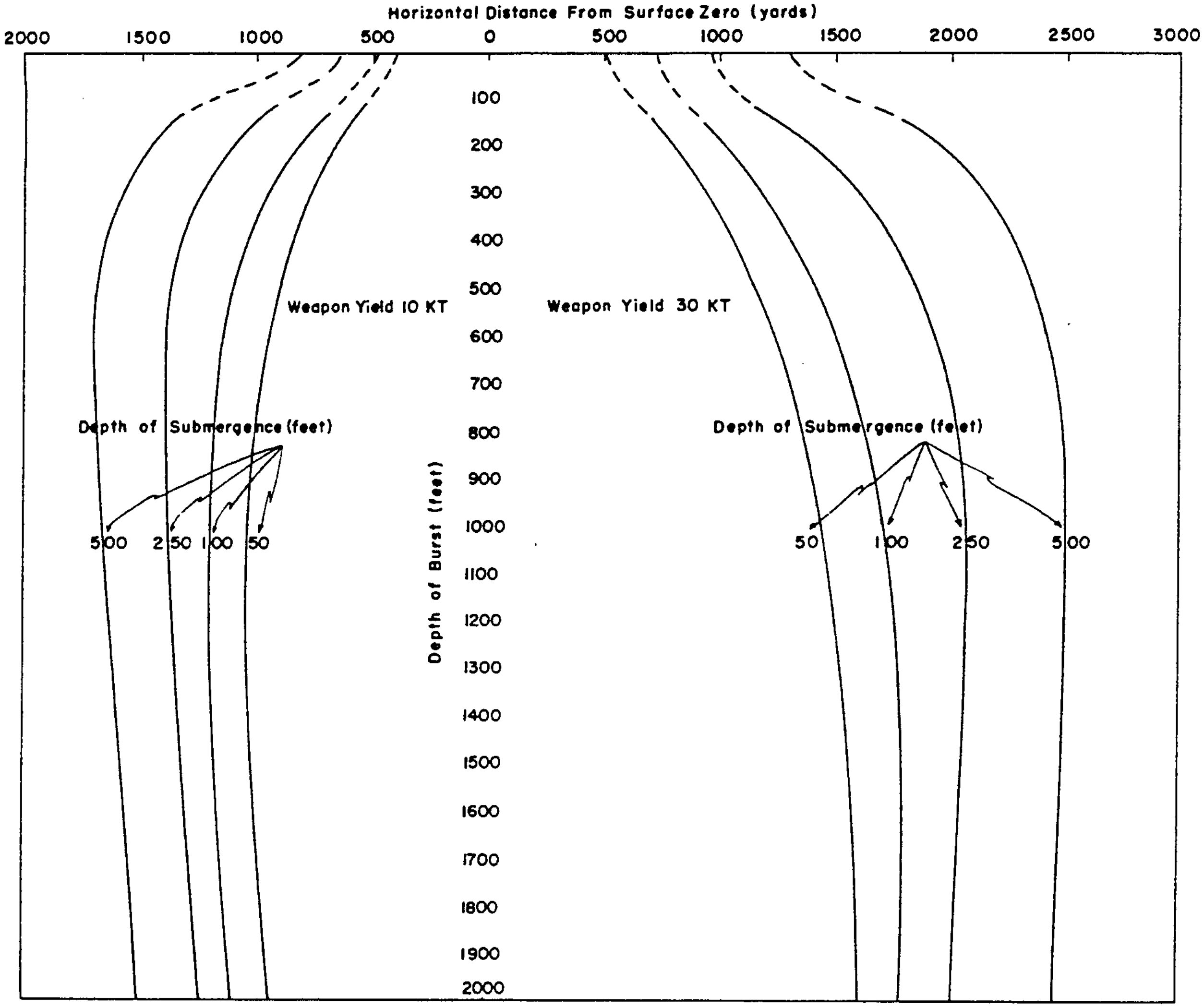
Related Material.

See paragraphs 8.1*c* and 8.3*a*.

See also figures 8-1 through 8-3 for surface ship damage.

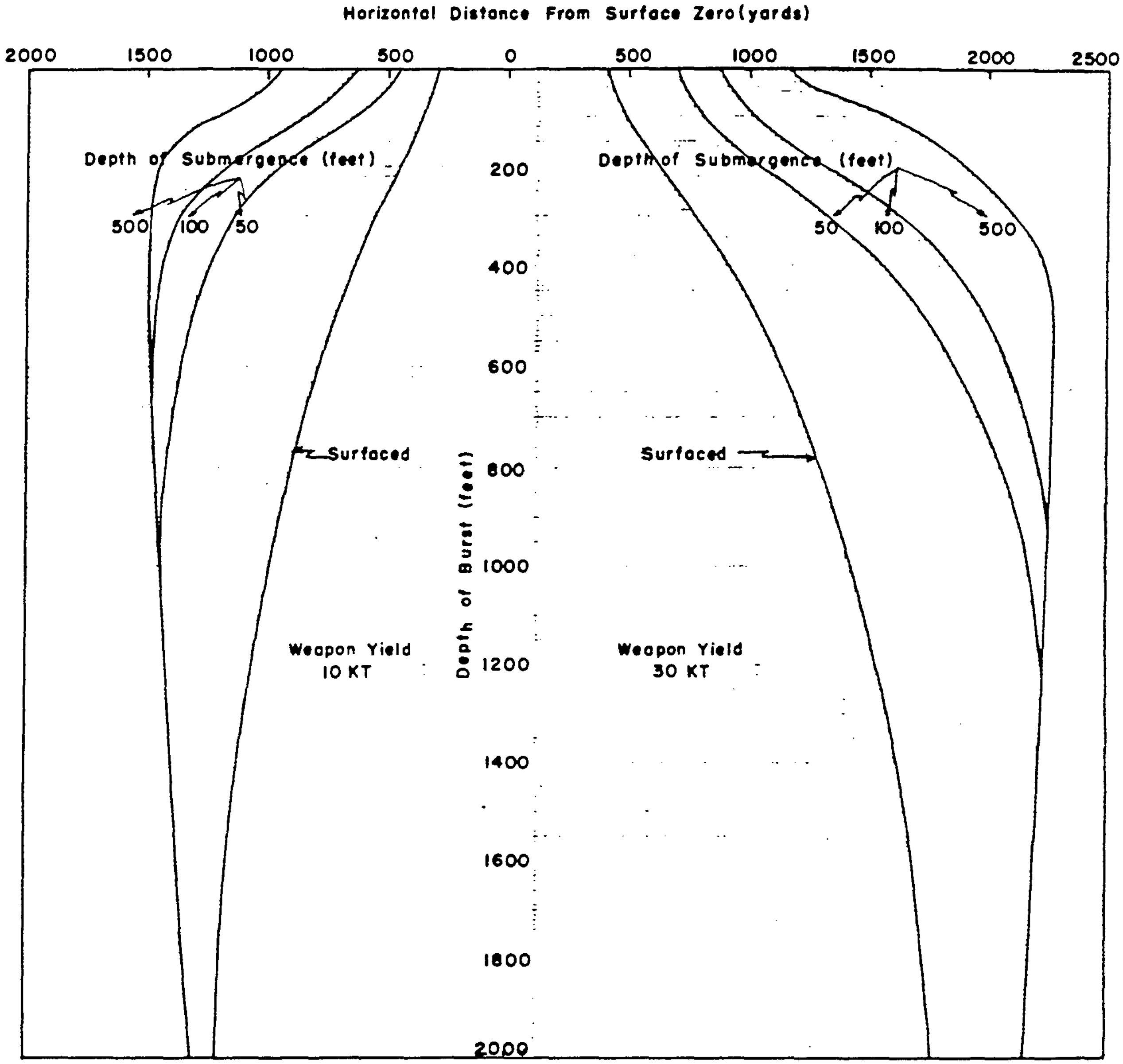
FIGURE 8-4

[redacted]



SUBMARINE LETHAL HULL DAMAGE BY 10KT AND 30KT
AS A FUNCTION OF DEPTH OF BURST AND HORIZONTAL RANGE

[redacted]



SUBMARINE INTERIOR SHOCK DAMAGE BY 10 KT AND 30 KT
AS A FUNCTION OF DEPTH OF BURST AND HORIZONTAL RANGE

UNDERWATER MINEFIELD NEUTRALIZATION

Figures 8–6 through 8–8 give ranges for underwater minefield neutralization as a function of yield for collapse pressures of 250, 500 and 1,000 psi with both the burst and mines on the bottom. Figure 8–6 is for a 50-foot water depth, figure 8–7 for 100 feet, and figure 8–8 for 200 feet. Linear interpolation between these curves can be used for intermediate water depths and mine case static collapse pressures.

Example.

Given: A 30 KT burst on the bottom in 100 feet of water.

Find· The range at which mines with a 500 psi static case collapse pressure located on the bottom are neutralized.

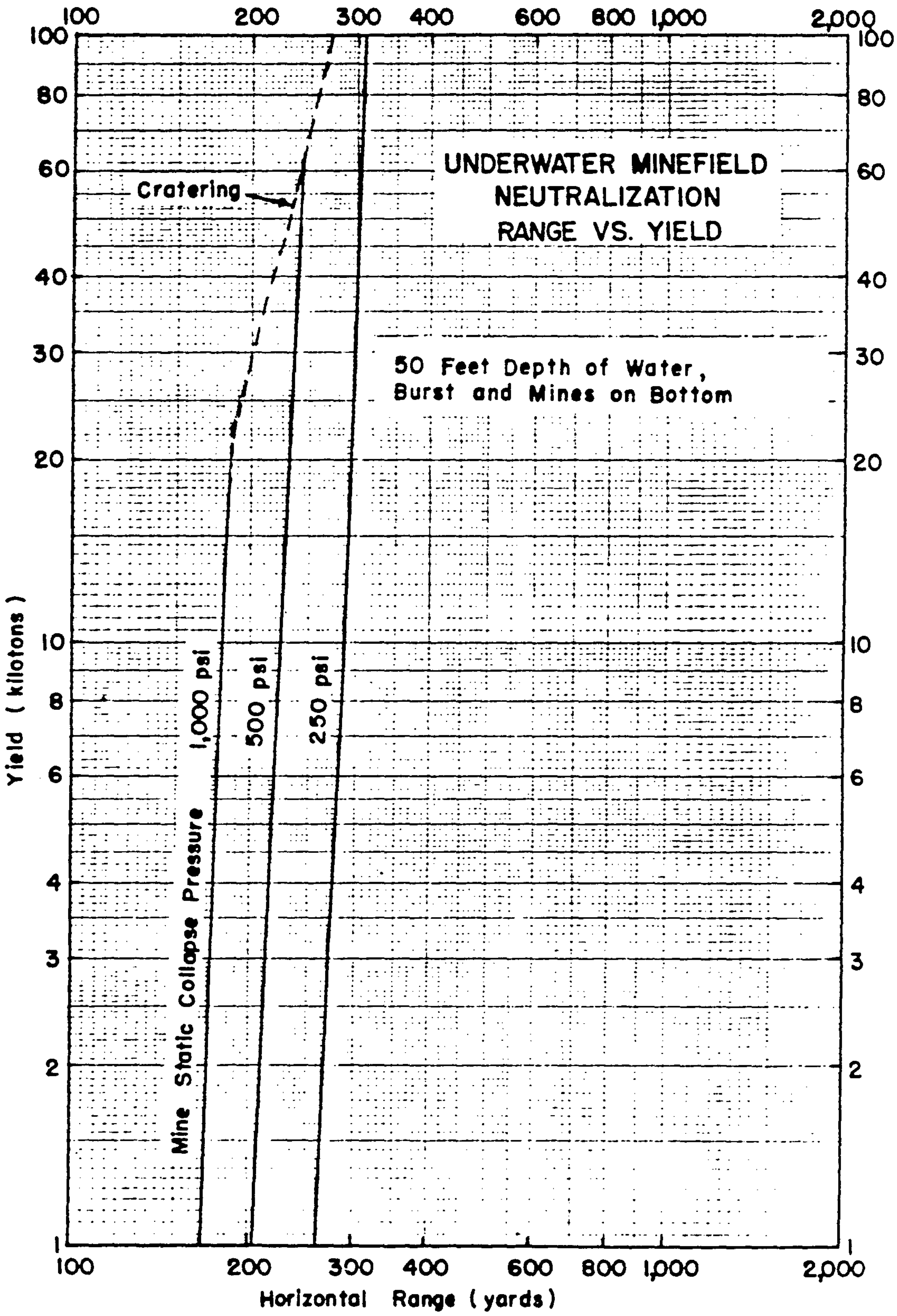
Solution: The range at which the mines are neutralized is taken directly from figure 8–7 to be 400 yards. *Answer.*

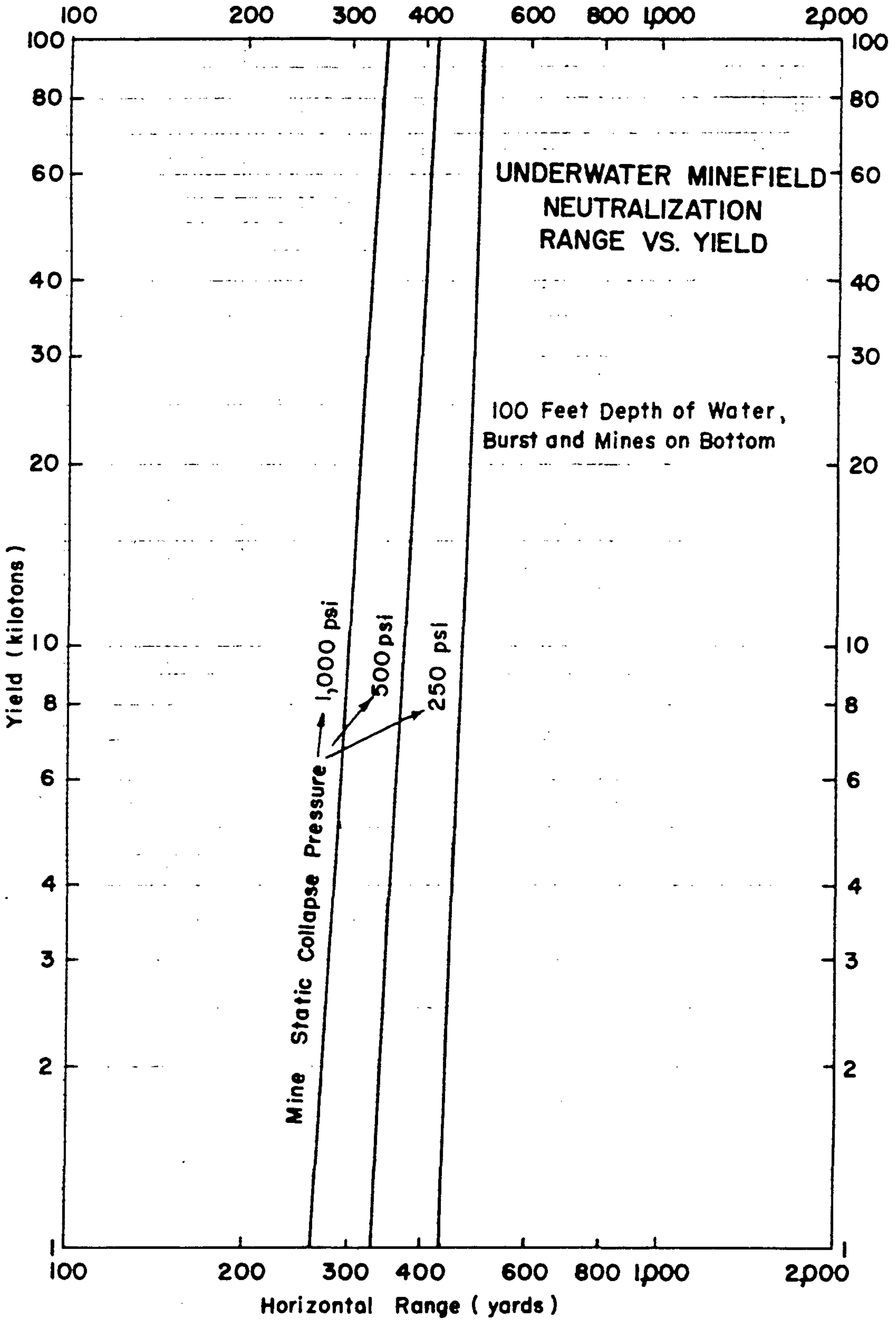
Reliability. Based on limited data.

Related Material.

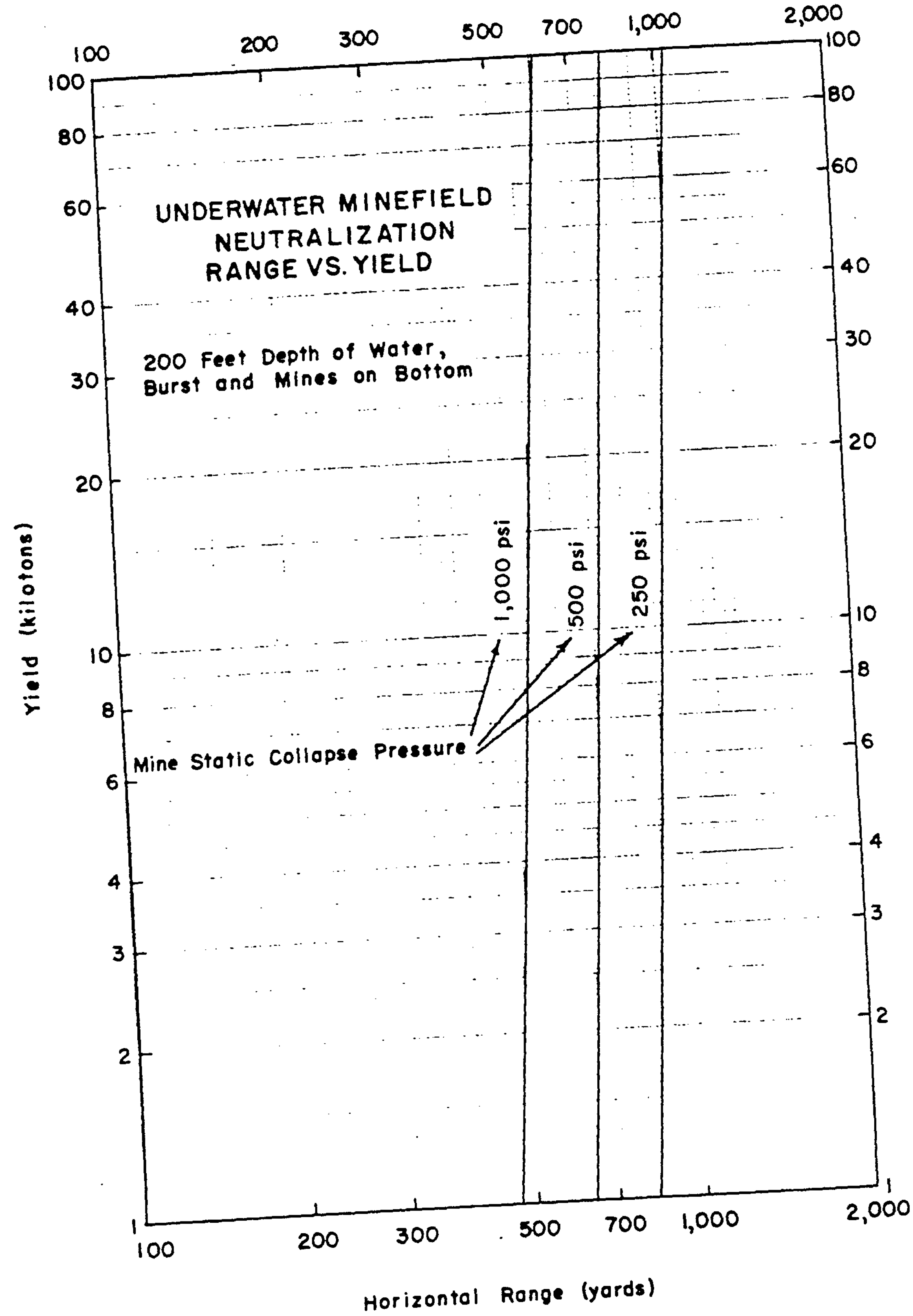
See paragraph 8.3*b*.

FIGURE 8-6


UNDERWATER MINEFIELD
NEUTRALIZATION
RANGE VS. YIELD
50 Feet Depth of Water,
Burst and Mines on Bottom
Cratering
Mine Static Collapse Pressure
1,000 psi
500 psi
250 psi
Yield (kilotons)
Horizontal Range (yards)
100
200
300
400
600
800
1,000
2,000
1
2
3
4
6
8
10
20
30
40
60
80
100


UNDERWATER MINEFIELD
NEUTRALIZATION
RANGE VS. YIELD
100 Feet Depth of Water,
Burst and Mines on Bottom
Mine Static Collapse Pressure
1,000 psi
500 psi
250 psi
Yield (kilotons)
Horizontal Range (yards)
100
200
300
400
600
800
1,000
2,000
1
2
3
4
6
8
10
20
30
40
60
80
100

~~CONFIDENTIAL~~



~~CONFIDENTIAL~~

DAMAGE TO NON-COMBAT AIRCRAFT

Figure 9–1 presents height of burst vs. ground range curves for light, moderate and severe damage to randomly oriented parked transport airplanes, light liaison airplanes, and helicopters. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria:

Light Damage--That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Transport airplanes, 1 psi; light liaison airplanes, ½ psi; helicopters, ½ psi.

Moderate Damage—That damage which requires field maintenance to restore the aircraft to operational status. Transport airplanes, 2 psi; light liaison airplanes, 1 psi; helicopters, 1½ psi.

Severe Damage—That damage which requires depot level maintenance to restore the aircraft to operational status. Transport airplanes, 3 psi; light liaison airplanes, 2 psi; helicopters, 3 psi.

Scaling. Height of burst and ground range for a given degree of damage scale as the cube root of the yield:

$$\frac{h_1}{h_2}=\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where h_1 and d_1 are height of burst and ground distance for yield W_1, and h_2 and d_2 are the corresponding height of burst and distance for yield W_2.

Example.

Given: A 100 KT weapon is to be burst at optimum height to obtain moderate damage to parked transport airplanes.

Find: The ground range at which moderate damage may be expected and the optimum height of burst.

Solution: From figure 9–1, the optimum height of burst for 1 KT is 1,300 feet. The optimum height of burst for 100 KT is $(100)^{1/3}\times 1300=6{,}000$ feet. *Answer*.

Also from figure 9–1, the ground range for moderate damage from a 1 KT burst at a height of burst of 1,300 feet is 1,380 yards. The corresponding ground range for 100 KT is $(100)^{1/3}\times 1{,}380=6{,}400$ yards. *Answer*.

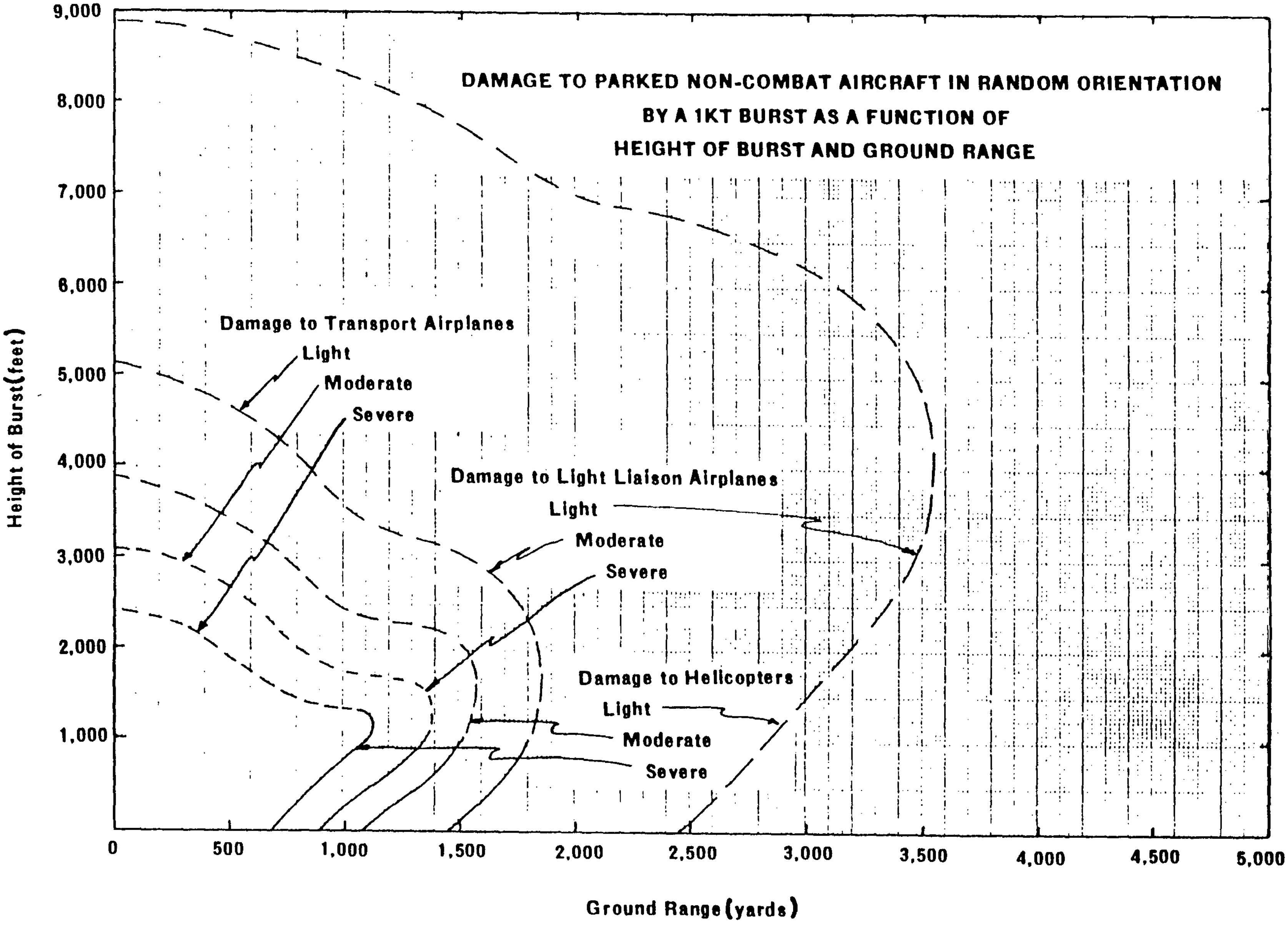
Reliability. These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

Related Material.

See paragraph 9.2.

See also figures 9–2 and 9–3.

FIGURE 9-1



DAMAGE TO PARKED NON-COMBAT AIRCRAFT IN RANDOM ORIENTATION BY A 1KT BURST AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

DAMAGE TO PARKED COMBAT AIRCRAFT, RANDOM ORIENTATION

Figure 9-2 presents height of burst vs. ground range curves for light, moderate and severe damage to bomber and fighter aircraft for random orientation. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria.

Light Damage—That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Jet bombers, 1½ psi; propeller fighters, 2 psi; jet fighters, 2 psi.

Moderate Damage—That damage which requires field maintenance to restore the aircraft to operational status. Jet bombers, 2½ psi; propeller fighters, 4 psi; jet fighters, 5 psi.

Severe Damage—That damage which requires depot level maintenance to restore the aircraft to operational status. Jet bombers, 4 psi; propeller fighters, 5 psi; jet fighters, 8 psi.

Scaling. Height of burst and ground range for a given degree of damage scale as the cube root of the yield:

$$\frac{h_1}{h_2}=\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where h_1 and d_1 are height of burst and ground distance for yield W_1, and h_2 and d_2 are the corresponding height of burst and distance for yield W_2.

Example.

Given: A 50 KT burst at ground level.

Find: At what range from ground zero must a jet fighter be parked in order to be no more than lightly damaged.

Solution: From figure 9-2, the distance from ground zero for light damage to jet fighters for a 1 KT burst is 900 yards. The corresponding distance for a 50 KT burst is $900\times(50)^{1/3}=3{,}300$ yards. *Answer.*

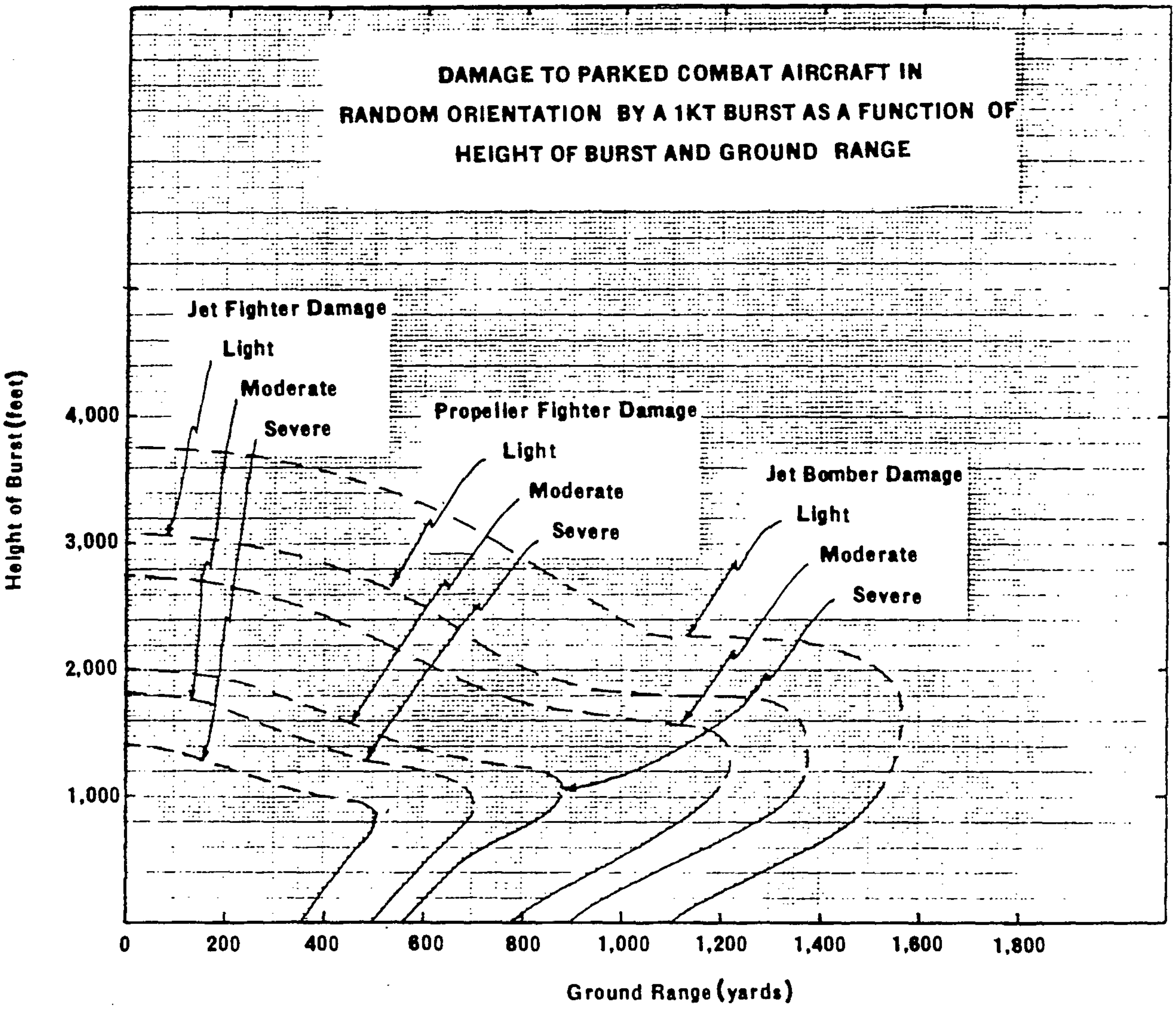
Reliability. These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

Related Material.

See paragraph 9.2.

See also figures 9-1 and 9-3.

FIGURE 9-2



DAMAGE TO PARKED COMBAT AIRCRAFT IN RANDOM ORIENTATION BY A 1KT BURST AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

DAMAGE TO PARKED COMBAT AIRCRAFT, NOSE-ON ORIENTATION

Figure 9-3 presents height of burst vs. ground range curves for light, moderate and severe damage to bomber and fighter aircraft for nose-on orientation. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria.

Light Damage—That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Jet bombers, 2 psi; propeller fighters, 2 psi; jet fighters, 3 psi.

Moderate Damage—That damage which requires field maintenance to restore the aircraft to operational status. Jet bombers, 3 psi; propeller fighters, 5 psi; jet fighters, 7 psi.

Severe Damage—That damage which requires depot level maintenance to restore the aircraft to operational status. Jet bombers, 5 psi; propeller fighters, 7 psi; jet fighters, 9 psi.

Scaling. Height of burst and ground range for a given degree of damage scale as the cube root of the yield—

$$\frac{h_1}{h_2}=\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}},$$

where h_1 and d_1 are height of burst and ground distance for yield W_1, and h_2 and d_2 are the corresponding height of burst and distance for yield W_2.

Example.

Given: A 30 KT weapon is burst 4,000 feet above the terrain and a horizontal distance of 2,500 yards from a jet bomber parked nose-on to the burst.

Find: The corresponding 1 KT height of burst and the degree of damage to be expected.

Solution: The corresponding 1 KT height of burst is $\frac{4{,}000}{(30)^{1/3}}=1{,}290$ feet.

The corresponding distance from ground zero is $\frac{2{,}500}{(30)^{1/3}}=800$ yards.

From figure 9-3, moderate to severe damage would be expected at 2,500 yards from ground zero for a 30 KT weapon burst 4,000 feet above the terrain. *Answer.*

Reliability. These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

Related Material.

See paragraph 9.2.

See also figures 9-1 and 9-2.

ESTIMATES OF GUSTS AND THERMAL ENVELOPES FOR TYPICAL COMBAT AIRCRAFT

Figure 9-4 presents an estimate, for each of three typical combat aircraft types, of the lethal envelope in the vertical plane containing the flight path. For each diagram, the silhouette represents the position of the aircraft at burst time; a 1 KT burst anywhere within the envelope is expected to destroy the aircraft. The corresponding lethal volume is approximately that within the surface of revolution generated by revolving the envelope shown about the flight path axis. Also indicated on the diagrams are the ranges at which the radiant exposure of the aircraft would be 135 cal/cm^2, an exposure level at which most aircraft would experience some melting of skin panels by thermal radiation from a 1 KT burst.

Scaling and Reliability. Estimates of lethal envelopes for other yields may be made by scaling the ranges to the blast envelopes by the cube root of the yield and the ranges for the 135 cal/cm^2 envelopes by the square root of the yield. The diagrams are presented to illustrate general shapes and sizes of lethal envelopes for aircraft and it is not intended that the numerical data be applied directly to any specific aircraft models.

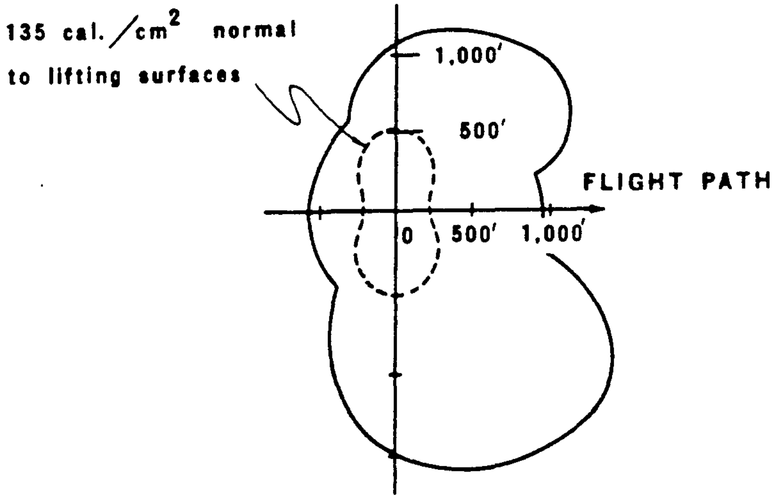
Related Material.

See paragraph 9.3.

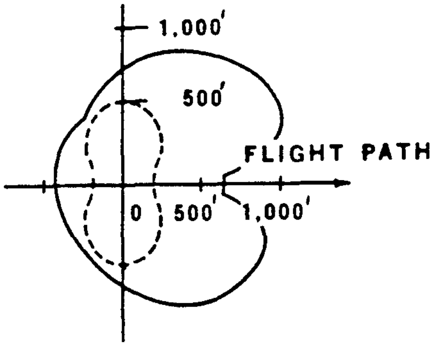
FIGURE 9-4

ESTIMATES OF GUSTS & THERMAL ENVELOPES FOR TYPICAL COMBAT AIRCRAFT

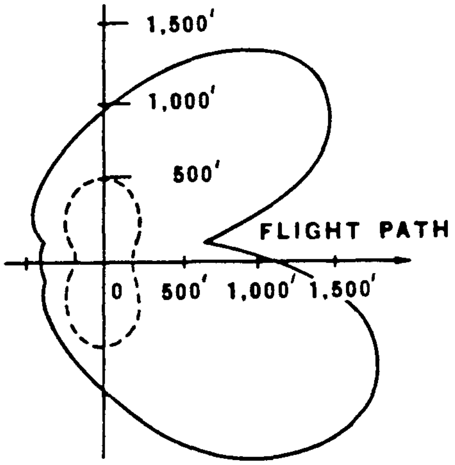
1 KT ANTI-AIRCRAFT BURST



SUBSONIC BOMBER
ALTITUDE 40,000′
SPEED, MACH .9



FIGHTER
ALTITUDE 40,000′
SPEED, MACH .95



SUPERSONIC BOMBER
ALTITUDE 70,000′
SPEED, MACH 2.5

SECTION XI
FOREST STANDS

11.1 General

Although forests or tree stands may afford troops deployed therein significant protection against certain effects of nuclear weapon detonations (e. g. thermal radiation), the forests themselves are quite vulnerable to some of these effects. Falling limbs and trees create a missile hazard and the resultant debris on the forest floor may impede the movement of troops and most vehicles. In dry, windy weather, forest fires may be initiated by a nuclear weapon detonation, with smoke and flame extending the range of hazardous effects from the bomb itself many times. Forest vulnerability depends on recent local weather history and upon the type of tree stand involved. Forest kindling fuels and types of stands are discussed in detail in the paragraphs which follow.

11.2 Air Blast

a. General. For convenience in discussion of blast effects, forest stands are divided into the following types:

(1) *Type I stand: Improved natural or planted conifer forests of European type.* These forests characteristically grow in regular blocks, usually with definite borders. Tree spacing is uniform with only small patches of ground visible through the canopy from above. Trees are of uniform height (100 to 130 feet) and nearly the same in diameter (14 to 24 inches). Stands of this type are vigorous in appearance and fast growing. Viewed from above the crown canopy appears smooth. Within the stand there usually will be found low stumps resulting from thinning, clear lower stems as a result of pruning, and little or no underbrush, combining to give the interior of the stand a clean park-like appearance, and affording good visibility and easy passage into the forest.

(2) *Type II stand: Naturally occurring, unimproved conifer forests that have developed under unfavorable growing conditions.* Unfavorable growing conditions result from: shallow and/or rocky soil, deficient annual rainfall, short growing season with unfavorable temperatures (i. e., higher latitudes and/or higher elevations), and unfavorable topography such as poorly drained flats or steep slopes. Random tree spacing is characteristic, with trees varying in height (10 to 75 feet) and in diameter (1 to 17 inches). The crown canopy generally has an uneven appearance. Large stands often contain bare areas with irregular borders. The stand itself appears low in vigor. The forest floor within the stand is generally cluttered with dead, fallen trees which, when combined with the persistent dead limbs on the dense growing live stems and the heavy underbrush in the numerous stand openings, impede entrance into the stand and decrease visibility.

(3) *Type III stand: All broadleaf forests and naturally occurring, unimproved conifer forests that have developed under favorable growing conditions.* Favorable growing conditions are associated with: deep, generally rock-free soil, adequate annual rainfall, long growing season with favorable temperatures (i. e., middle latitudes and lower elevations), and favorable topography such as well-drained flats and moderate slopes, or along stream courses. Random tree spacing is characteristic with trees varying in height (30 to 120 feet) and in diameter (2 to 25 inches). The crown canopy generally has an uneven appearance. Large stands often contain bare areas with irregular borders. The stand itself appears high in vigor. The forest floor within the stand may be

cluttered with dead, fallen trees which impede entrance into the stand. Underbrush is light or absent, and visibility is fairly good.

b. Air Blast Damage. Height of burst-damage-distance curves for severe and light damage to forests are presented in figures 11–1 to 11–6. Distances to which a given level of damage from a subsurface burst occurs may be derived from figure 7–18 in conjunction with these figures. Examples of scaling accompany figure 11–1. Tree stand types referred to are those given above. Severe and light damage are defined in terms of length of stems down per acre; approximately 1,500 feet per acre for light damage and 9,000 feet per acre for severe damage. These criteria in terms of percentage of trees broken are shown in table 11–1. The approximate number of trees per acre that may be expected for the three stand types is also shown.

Table 11–1. Percentage of Trees Broken for Light and Severe Damage to Forest Stands

Stand type	Total No. of trees per acre	Trees per acre 6 in. or larger in diameter	Light damage, % trees 6 in. or larger in diameter, broken	Severe damage, % trees 6 in. or larger in diameter, broken
I	75	75	15	95
II	475	260	[a] 10	[a] 65
III	215	200	[b] 10	[b] 60

[a] Majority of damage as uprooted trees.
[b] In broadleaf forests majority of damage as branch breakage and uprooting

11.3 Thermal Radiation

a. General. Under certain conditions, the employment of an air burst weapon over a forest or wildland area may cause fires. During the fire season, even when the burning potential (a measure of probable fire aggressiveness) is low, fires may spread. If fires are started in regions of sufficient fuel density when the burning potential is dangerously high, complete evacuation of personnel and equipment may be necessary. Organized control of the spread of the fire is virtually impossible until changes in weather or fuel availability reduce the burning potential.

b. Ignitions. Wildland fuels are generally a mixture of thin and heavy fuel components. Thin fuels are typified by surface litter and grassland; heavy fuels by fallen branches. The thinnest fuel present determines the exposure required for ignition of the mixture. Heavy fuels do not ignite and continue to burn by themselves; however, thin fuels may serve as the source of a pilot flame which substantially lowers heavy fuel ignition exposure requirements, or thin fuels may spread fire after the end of the thermal pulse. During the fire season, ignitions may be expected in kindling fuels wherever the radiant exposures exceed 2 to 3 cal/cm^2 for a 1 KT weapon. As the yield increases the minimum radiant exposures for ignition increase as $W^{1/8}$, i. e., 8 to 10 cal/cm^2 would be required from a 30 MT weapon to ignite the thinnest wildland fuels. These exposures apply to surfaces normal to the direction of radiation; however, wildland fuels rarely present a flat smooth surface. Individual fuel particles are of many shapes and are oriented more or less at random. Consequently, even at low burst altitudes, minimum ignition exposures can be assumed to remain the same, although a reduced number of ignitions is to be expected owing to the increased shielding effect of trees and shrubs. Green leaves and needles on tree crowns smoke and char but do not ordinarily sustain ignition. This smoke production materially reduces the radiant exposure of the ground surface. Ignitions occur in open areas if the dimensions are large enough so that the area is not completely in the shadow of adjacent timber or brush stands. It is estimated that very few ignitions occur within a timber stand in which the tree canopy shades more than 20 percent of the ground surface. Smoldering ignitions are likely to occur in snags and dead limbs on the forest floor. While such ignitions are not an immediate hazard, they may cause fires to break out up to two or three days later, especially if a large amount of blast breakage occurs, opening the stand to the prevailing winds.

c. Fire Seasons. The fire season of an area is primarily a function of the annual rainfall-temperature pattern and its associated vegetation development, and varies widely between geographic locations. Table 11–2 summarizes these conditions for the more important wildland fuels found throughout the world. Once it is determined that fuel conditions meet those prevailing in the fire season, local weather conditions will determine burning potential.

Table 11-2. Condition of Wildland Fuels During Fire Season

Fuel type		Amount and density of fuel required to constitute a fire hazard	Condition during fire season
Grass or heath	Grassland; dry bracken ferns and other seasonal plants; dry regrowth in previously burned areas.	Uniform grass cover one-half ton or more per acre.	Vegetation nearly cured or dead.
Evergreen brush	Perennial evergreen shrubs and brush; chaparral; young evergreen growth.	75 percent or more area covered.	15–25 percent by weight of leaves and associated twigs dead.
Deciduous broadleaf forest.	Forest predominantly of trees such as oak, birch, maple, etc., leaves of which die and fall every year.	Ground covered with more or less continuous layer of dead leaves.	Leaves off trees; ground vegetation dead or nonexistent.
Coniferous forest	Forest of evergreen pines, firs, spruces, etc.; generally the family of needle bearing trees.	Ground covered with more or less continuous layer of dead needles and twigs.	Needles and twigs dry enough to break easily when bent. Grass and other ground vegetation, if present, curing or dead.

d. Kindling Fuels. The majority of thin wildland fuels which serve as kindling material are typed as shown in table 11-3 into four classes corresponding to different minimum exposures required for ignition. Ignition exposures required increase as fuel moisture content increases. Since ignition generally occurs on those surfaces most exposed to the atmosphere, required ignition exposures are a function of relative humidity as shown in figure 11-7. Fires may be blown out by the blast wave, depending on the time interval between ignition and arrival of the shock. Blowout is not expected in overpressure regions below 5 psi for fully exposed fuels. When fires are not blown out, they generally increase in intensity due to action of the blast wind.

Table 11-3. Classes of Thin Wildland Kindling Fuels (Arranged in Order of Decreasing Flammability)

Class	Description
I	Broadleaf and coniferous litter—mixture of fine grass, broken leaves and duff, and thin translucent broadleaf leaves.
II	Hardwood and softwood punk in various stages of decay.
III	Cured or dead grass.
IV	Conifer needles and thick, nearly opaque broadleaf leaves.

e. Burning Potential. The principal factors, aside from the fuels present, that influence the burning potential of a forest or wildland area are—the nature of the terrain, the wind speed close to the ground, the relative humidity and the precipitation history. An approximate guide for evaluating the effects of weather on burning potential is given in table 11-4. Fuels seldom burn vigorously, regardless of wind conditions, when the fuel moisture is greater than 16 percent. This corresponds to an equilibrium moisture content for 80 percent relative humidity. About a quarter inch of rain renders fuels temporarily nonflammable and may extinguish going fires in thin fuels. The time required to restore the burning potential to the value prior to the rain may vary from hours to days depending on local weather conditions. Surface fuels in the interior of timber stands are exposed to reduced wind velocities and generally have high fuel moisture due to shading by the canopy.

f. Fire Spread. Under identical weather conditions, concentrations of heavy fuel are more hazardous than thin fuels, even though they tend to reduce local wind speeds and do not respond as rapidly to changes in relative humidity. Trees and heavy limbs on the forest floor may be ignited by an otherwise nonhazardous surface fire. When heavy fuels are present near the borders of standing timber, fire may travel into the tree crowns and continue to crown (spread

Table 11–4. Burning Potential for Light Wildland Fuels During Fire Season (Terrain With Slopes Less Than 20 Percent)

Wind speed at 20 feet above ground in the open	Relative humidity (percent)			
	Below 15	15–40	40–65	65–80
Below 5 knots	Dangerous*	Dangerous	Low*	Low.
5–10 knots	Critical*	Dangerous	Dangerous	Low.
10–15 knots	Critical	Critical	Dangerous	Low.
Above 15 knots	Critical	Critical	Critical	Dangerous.

*Definitions:

Low—irregular fire perimeter, spread greatly affected by local changes in fuel structure and topography, depth of fire small. Fire generally stops at roads and ridge tops. Control action can be on an individual basis.

Dangerous—continuous intense fire front which moves rapidly, frequently spots ahead. Aggressive organized action required to protect personnel and equipment.

Critical—conflagration-type fire, in heavy fuels readily crowns and spots as much as a mile ahead. Requires personnel and equipment to be evacuated from in front and from near the flanks of such fires. Control action effective only when changes in fuel type or burning conditions permit.

Note 1. For heavy fuels, use the classification for the next higher wind speed.
2. For terrain with slopes greater than 20 percent, use the classification for the next higher wind speed.
3. For canopy shading 20 percent of the ground, reduce wind one class and increase relative humidity one class.
4. For full shading, reduce wind two classes and increase relative humidity two classes.

from top to top) even though ground fuel concentrations are low. Pine species are most likely to crown, fir and spruce less likely, and hardwoods least likely. Where large areas of heavy dry fuels are ignited simultaneously, a large whirling fire may develop. Such fires exhibit erratic spread behavior. Whirls may break off the main fire and travel against the prevailing wind. Whenever a strong upward convection column is built up in the case of a heavy fuel fire, the fire may spread very rapidly by "spotting", i. e., by throwing firebrands. Fires started by spotting may travel toward the main fire due to strong indrafts.

DAMAGE TO FOREST STANDS BY TYPE

In figures 11–1 through 11–6 are shown severe and light damage curves for three types of forest stands. Severe damage is defined as approximately 9,000 feet of stems down per acre, and light damage is defined as approximately 1,500 feet of stems down per acre. These criteria in terms of percentages of trees broken in typical stands are shown in table 11–1.

For yields greater than 10 MT, the following scaling procedure applies for height of burst and ground range:

$$\frac{d_1}{d_2}=\frac{W_1^{1/3}}{W_2^{1/3}}=\frac{h_1}{h_2},$$

where d_1=distance for height of burst h_1, and for reference yield W_1, *which is 10 MT* ($10^{1/3}=2.15$); and d_2=distance for height of burst h_2, and for yield W_2 (where W_2 is *in megatons and greater than 10 MT*). This scaling procedure applies only to scaling 10 MT values to higher yields.

Example.

Given: A 20 MT burst at a height of 1,000 feet above a type 1 forest stand.

Find: To what distance light damage extends.

Solution: From the scaling given above,

$$\frac{h_1}{1{,}000}=\frac{2.15}{(20)^{1/3}}, \text{ so that}$$

$$h_1=\frac{2{,}150}{(20)^{1/3}}=790 \text{ feet},$$

the height of burst scaled to 10 MT. From figure 11–4, light damage to a type 1 stand exposed to a 10 MT burst at 790 feet extends to a ground range of 16,000 yards. Therefore, for a 20 MT burst at 1,000 feet, light damage extends to a ground range given by—

$$\frac{16{,}000}{d_2}=\frac{2.15}{20^{1/3}}, \text{ or,}$$

$$d_2=\frac{16{,}000\times 2.72}{2.15}=$$

20,200 yards. *Answer.*

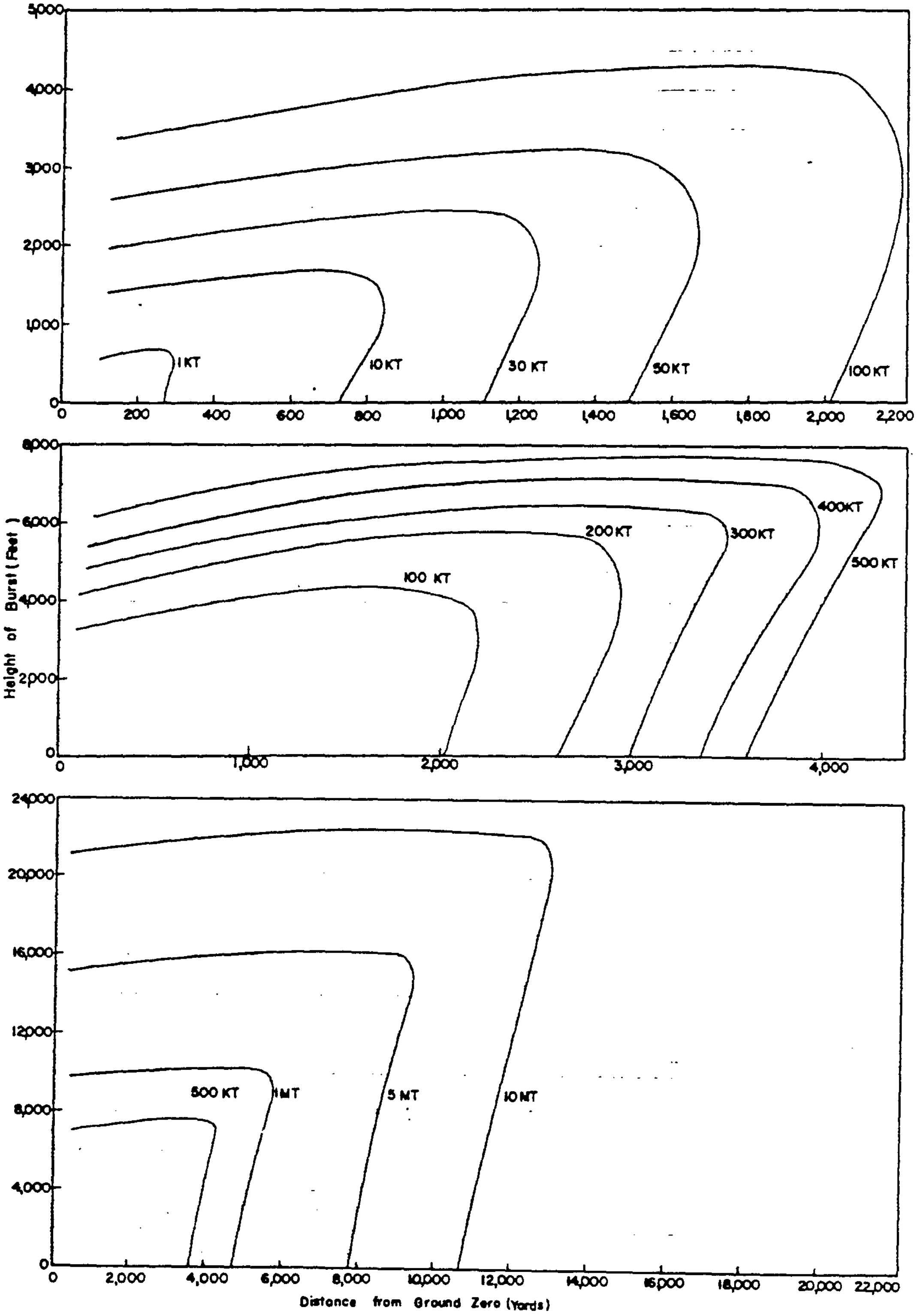
Reliability. Based upon observed results of limited full-scale tests and extensive laboratory experiments.

Related material.

See paragraph 11.2.

See also paragraph 11.3 and figure 11–7 for fire effects in forest stands.

SEVERE DAMAGE TO TYPE I FOREST STANDS AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



SEVERE DAMAGE TO TYPE II FOREST STANDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

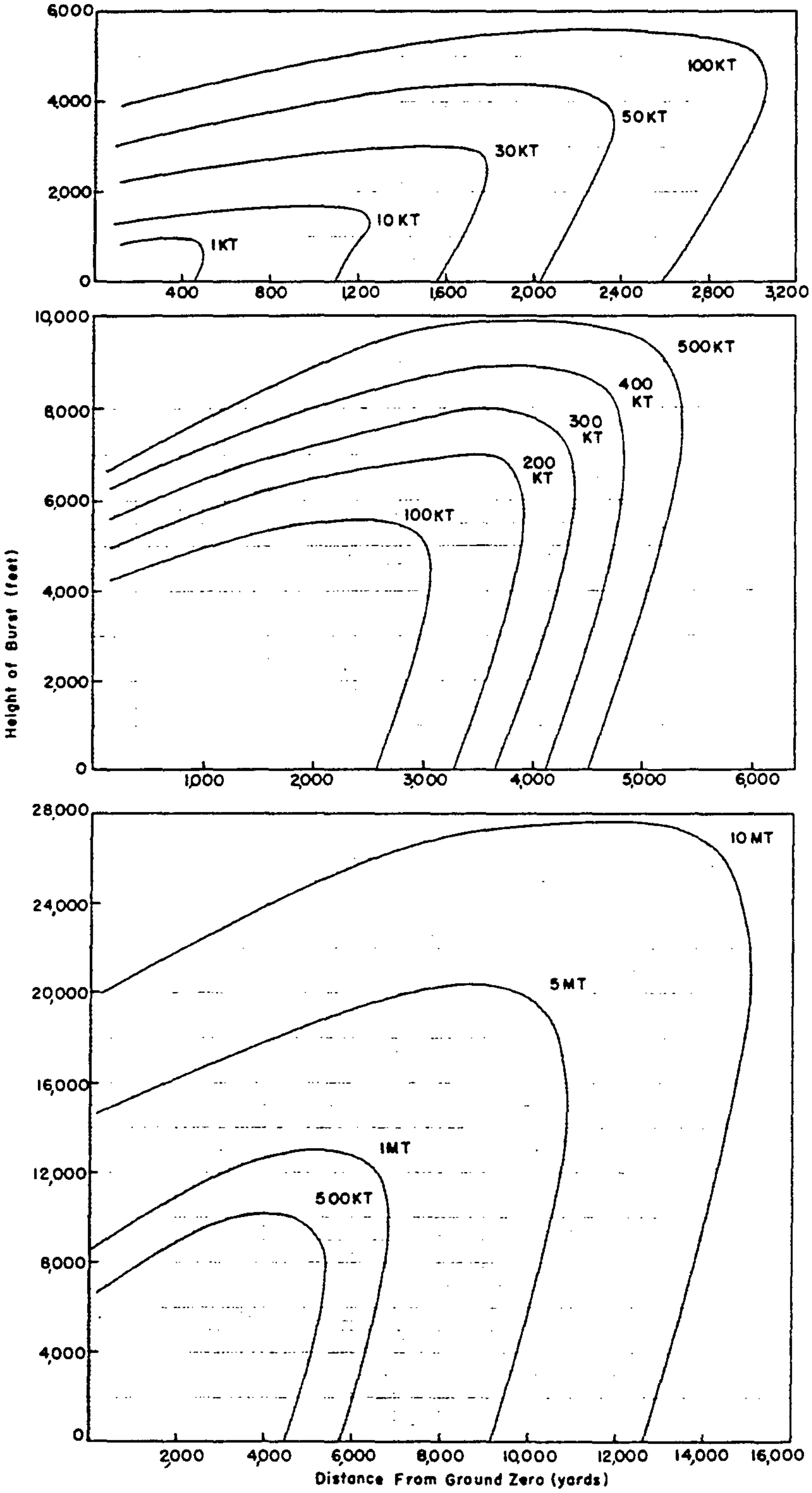


FIGURE 11-3

SEVERE DAMAGE TO TYPE III FOREST STANDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

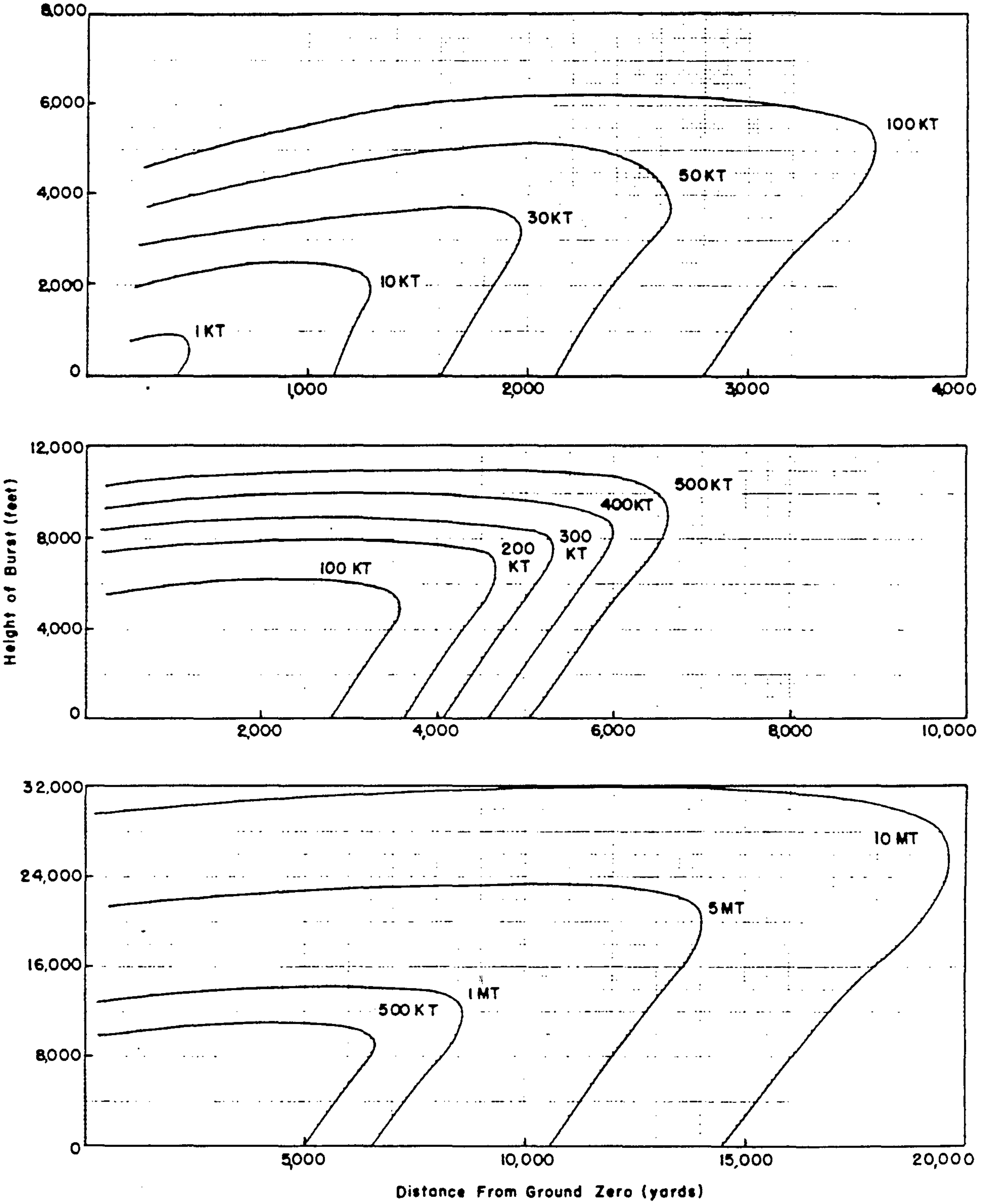


FIGURE 11-4

LIGHT DAMAGE TO TYPE I FOREST STANDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

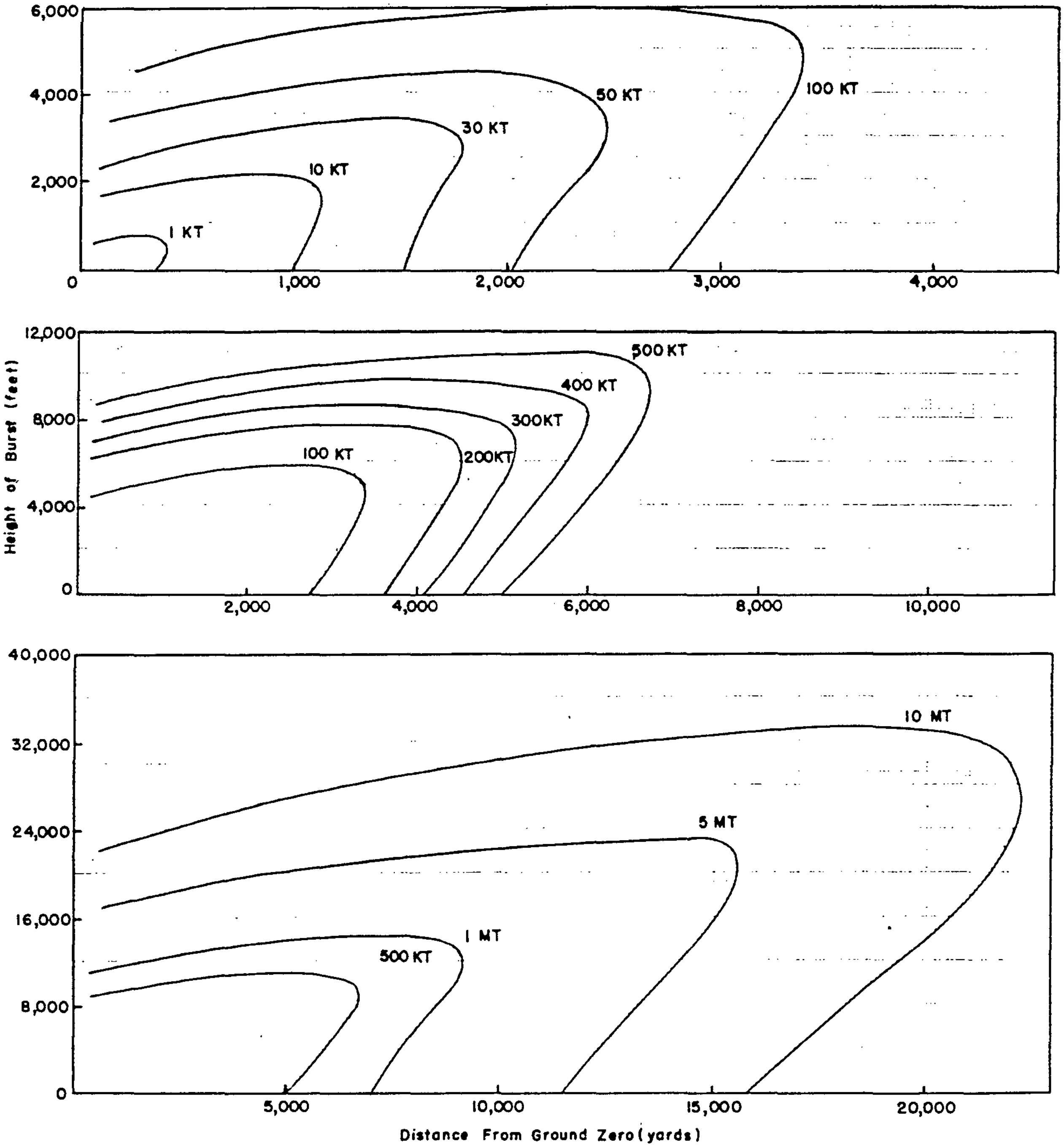
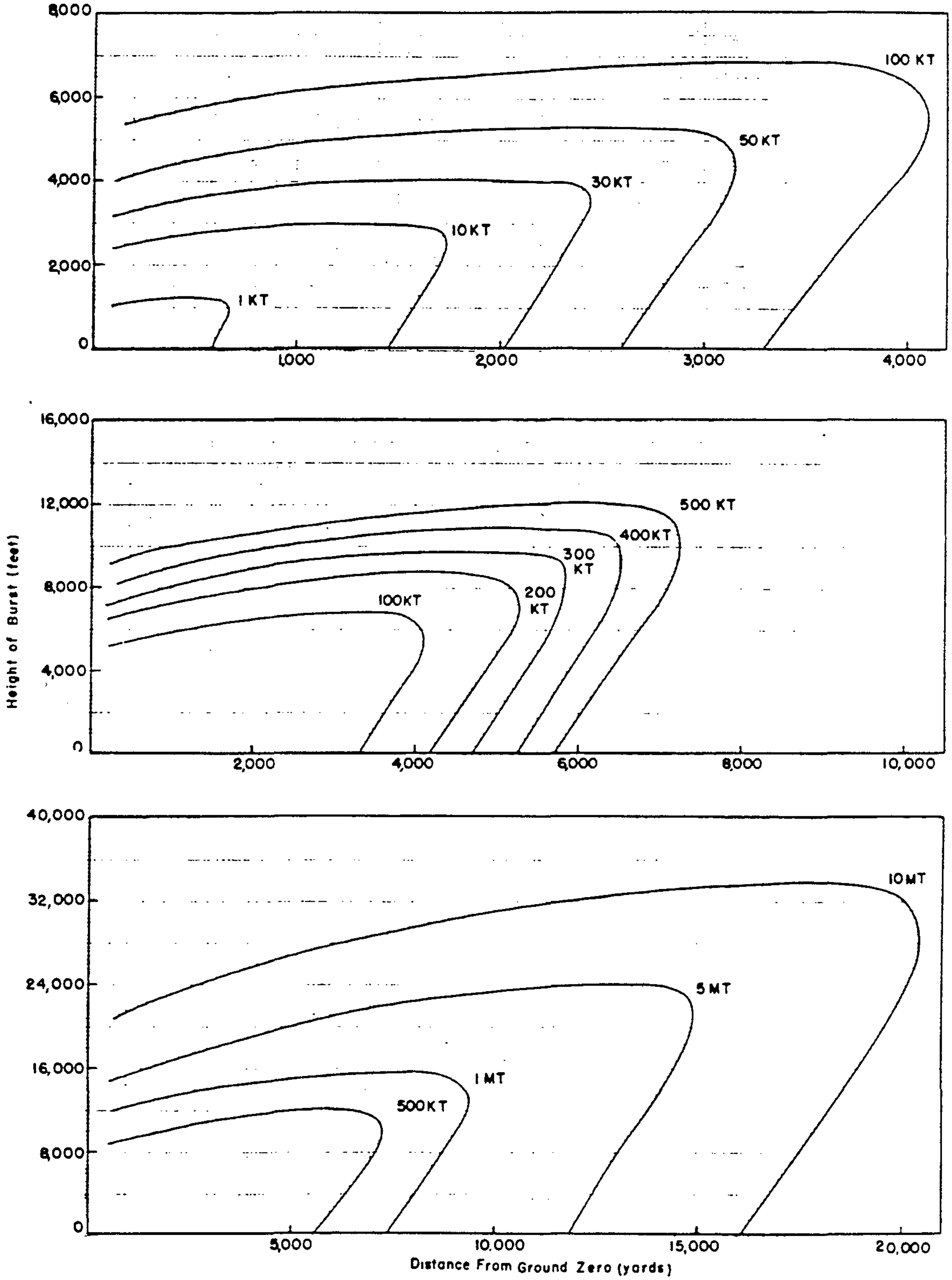
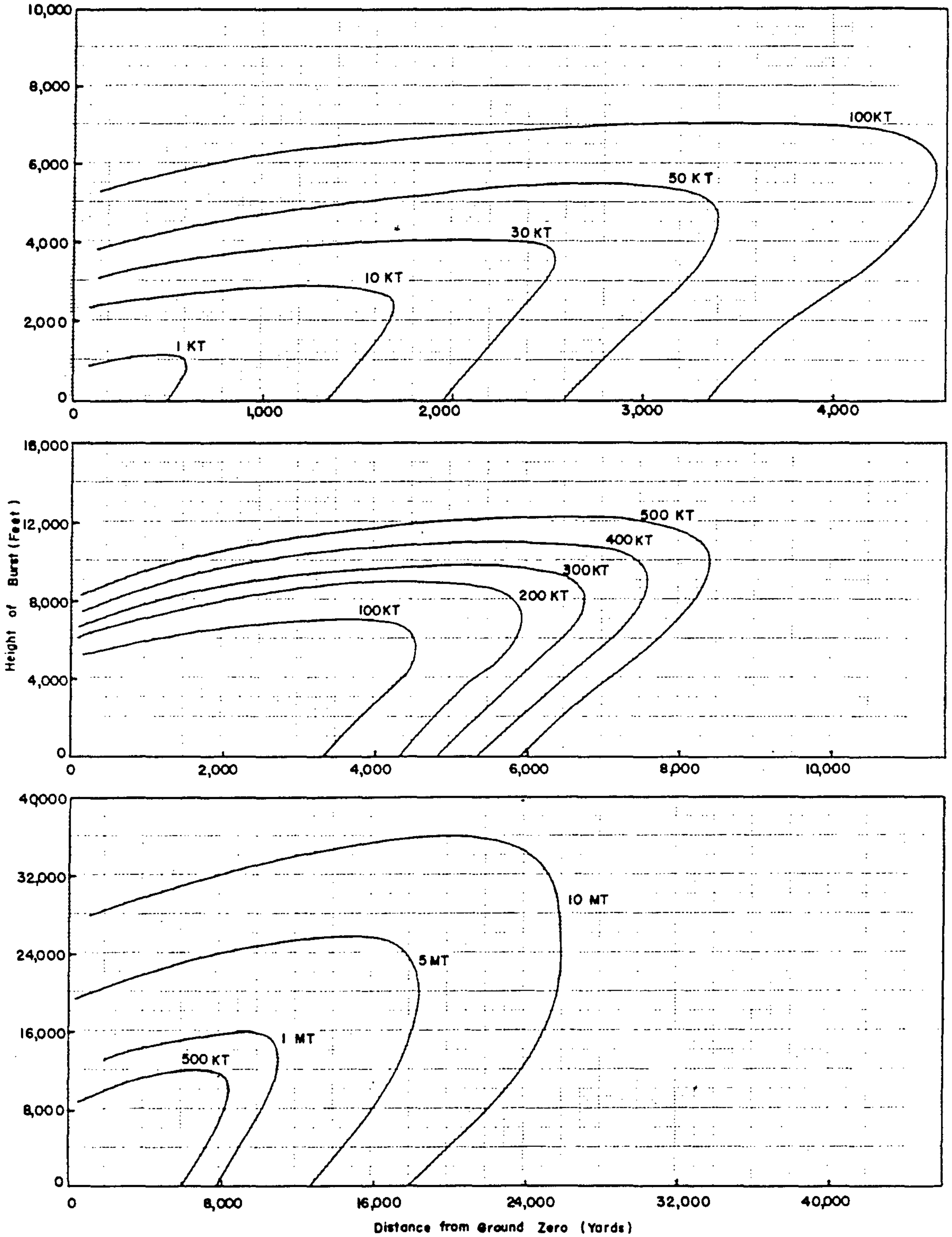


FIGURE 11-5

LIGHT DAMAGE TO TYPE II FOREST STANDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



LIGHT DAMAGE TO TYPE III FOREST STANDS
AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE



WILDLAND KINDLING FUEL IGNITION REQUIREMENTS

The curves of figure 11–7 are presented for various classes of kindling fuels described in table 11–3.

Scaling. To find minimum radiant exposures for another yield W, multiply the exposures read from figure 11–7 by $W^{1/8}$.

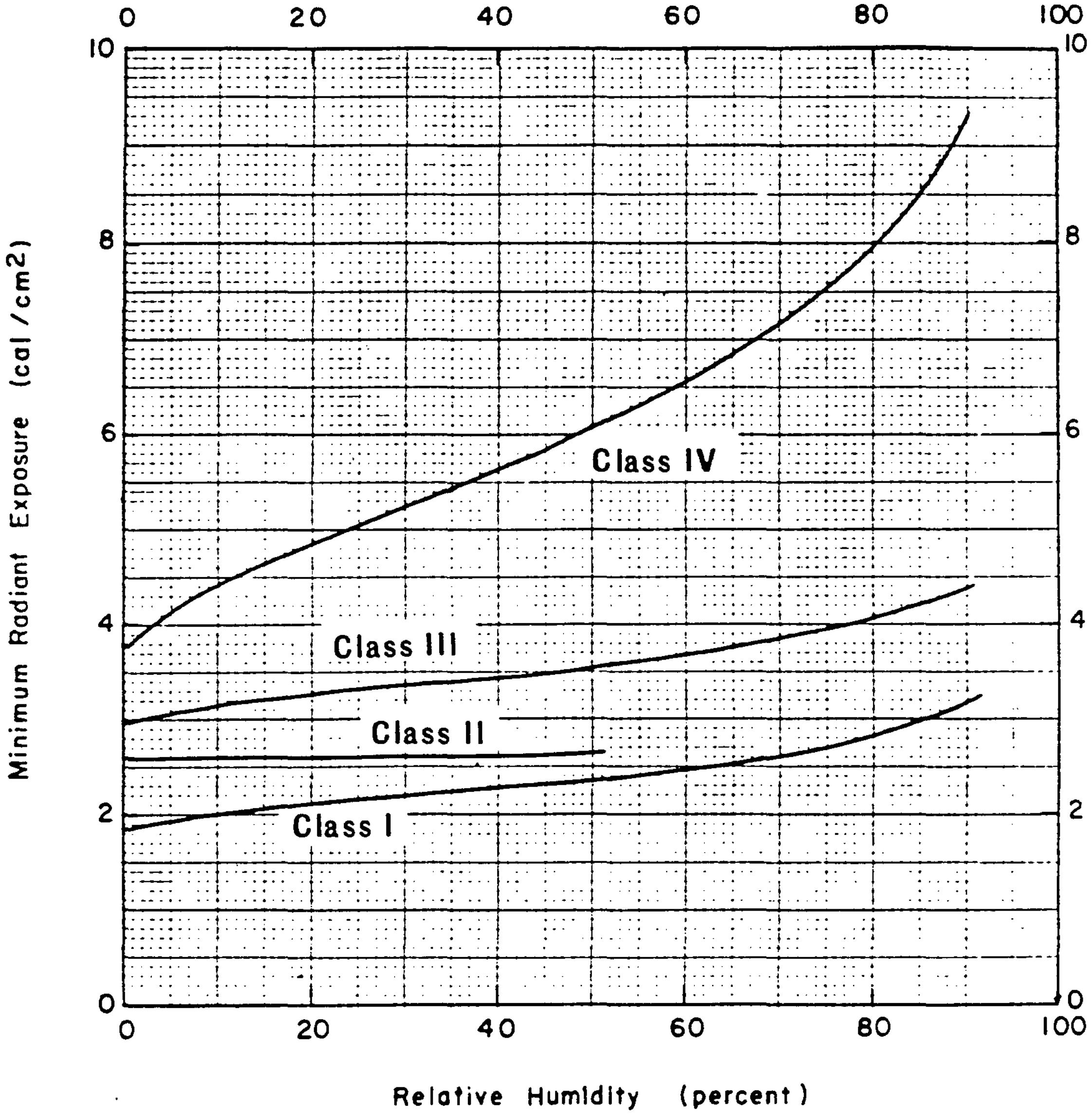
Reliability. Based upon observed results of limited full-scale tests and extensive laboratory experiments. The results are not considered reliable in the megaton range.

Related material.

See paragraphs 11.3*b* and 11.3*d*, and table 11–3.

See also figures 11–1 through 11–6 for air blast damage to forest stands.

MINIMUM RADIANT EXPOSURE FOR IGNITION OF WILDLAND KINDLING FUELS BY CLASS SCALED TO 1KT



SECTION XII
MISCELLANEOUS RADIATION DAMAGE CRITERIA

12.1 Fire in Urban Areas

a. General. The employment of an air burst weapon over urban areas may produce, in addition to blast damage, mass fires which under proper conditions materially increase the degree and extent of damage. The behavior of such fires, whether they are of primary or secondary origin, follows the pattern of fires in forest and wildland areas. The burning potential for urban areas varies with weather conditions in much the same manner as for wildlands; however, the fire season as such is not as pronounced as in wildlands. During those seasons when weather conditions may reduce exterior potentials to zero, dwellings are usually heated, so that interior fuels are dried out. Fire incidence and subsequent fire buildup depend also upon the amount and distribution of flammable material used in interior furnishing and building construction, the incidence of interior kindling fuels, and the relative cleanliness of the living habits of the population.

b. Ignition Points. A survey of metropolitan areas in the United States indicates that the incidence of exterior ignition points can be correlated with urban land use. Table 12-1 presents a relative tabulation based on exterior kindling fuels. Newspapers and other paper products account for 70 percent of the total, while dry grass and leaves account for another 10 percent in residential areas. Most other exterior kindling fuels are present in small percentages or require radiant exposures in excess of 10 cal/cm^2 for ignition. Weathered and badly checked fences and building exteriors which contain appreciable dry rot constitute an ignition hazard. The tabulation presented in table 12-1 is not representative of European cities and other areas where fuel is at a premium or where extensive use is made of stone, brick, masonry, and heavy timber construction. Multi-story buildings and narrow streets reduce both interior and exterior primary ignitions, since such ignitions are proportional to the amount of sky seen from the location of the probable ignition point.

Table 12-1. Relative Incidence of Ignitions in Metropolitan Areas of the United States by Land Use (Based on Exterior Kindling Fuels)

Land use	Relative incidence
Downtown retail	1.0
Large manufacturing*	1.4
Good residential	1.6
Small manufacturing	3.8
Poor residential	5.2
Neighborhood retail	5.5
Waterfront areas	8.0
Slum residential	11.7
Wholesale	15.1

*May be likened to a typical fixed military installation in the Z. I.

c. Humidity Effects. Since paper is the major exterior kindling fuel and is also an important interior fuel, the extent of ignitions may be estimated from the minimum radiant exposure requirements for this material (fig. 12-1). Thin exterior kindling fuels respond to hourly changes in relative humidity; however, fire buildup and subsequent fire behavior are best estimated from the average daytime relative humidity. Maximum fire effects occur during daily periods of lowest relative humidity, usually mid-afternoon. Guides for estimating urban burning potentials are given in figures 12-2 and 12-3. Where central heating of dwellings is a common practice, interiors are much drier than would be indicated by exterior relative humidities and temperatures. Based on United States experience, interior heating becomes an important factor when the maximum daily temperature drops below 70° F. Where fuel is scarce or expensive, this temperature may drop to 60° F., or even lower.

d. Fire Spread. The rate of fire buildup in urban areas is expected to be slower than for wildlands. The time to maximum fire intensity is less for the relatively high ignition incidence areas of table 12-1 than for those of lower ignition incidence. Aside from weather conditions, the principal factors which influence fire spread are the continuity, size and combustibility of buildings, fuel value of building contents, and topography. When strong convective action develops and spotting is frequent, the flammability of roof material is an important factor in spread. Spread of the fire front generally occurs by radiation from adjacent buildings; hence, fire stops only when the building spacing becomes great enough to reduce this radiation level below a critical value. This critical spacing is greater for multi-story buildings and varies with building combustibility, but on the average is about 50 to 100 feet.

12.2 Nuclear Radiation Damage

a. Neutron Irradiation.

(1) *Free air neutron flux.* The curves in figure 12–4 show the number of fast neutrons per square centimeter expected per kiloton of yield at various horizontal distances from typical airburst fission weapons detonated at altitudes up to 100,000 feet MSL. It is believed that these curves will give results correct within a factor of five.

(2) *Permanent damage.* Except for photographic film, which is clouded by neutron interaction with particles in the emulsion, and for electronic equipment which utilizes transistors, no permanent damage to equipment results from neutron irradiation. There is evidence that exposure to a neutron flux in excess of 10^{11} neutrons per square centimeter permanently alters the characteristics of transistors. However, any electronic equipment exposed to this flux of neutrons from a nuclear weapon detonation is likely to be severely damaged or destroyed by other effects. Discoloration of glass by neutrons does not occur for fluxes less than about 10^{18} neutrons per square centimeter, and thus can be disregarded as a significant effect.

(3) *Induced activity.* If the neutron flux is sufficiently high, a certain amount of neutron induced gamma activity results for most articles made of steel, due to the manganese which is usually present in commercial steels. The induced activity presents no personnel hazard except for articles exposed within or almost within the fireball, and even then the activity decays so rapidly as to be negligible less than a day after exposure. Significant neutron induced beta activity results in articles made of brass or other copper alloys, if exposed in or near the fireball. The personnel hazard is negligible unless the articles are handled very soon after the detonation. Radioactive decay reduces the activity to negligible levels within a few days.

b. Gamma Radiation. In general, massive quantities of gamma radiation are required to produce any damage to materials, so that damage by some other weapon phenomenon is nearly always more significant. Gamma radiation in excess of 10,000 roentgens can cause deterioration of rubber and other polymers as evidenced by a decrease in breaking strength. Exposure of glass to very high quantities of gamma radiation can produce discoloration. The intensity of radiation required is so great that this may be disregarded as a significant effect. Gamma rays, unlike neutrons, induce negligible radioactivity in materials; therefore, no residual radiation hazard is caused by initial gamma radiation.

c. Electromagnetic Radiation. A large electrical signal is produced by a nuclear weapon detonation. The signal consists of a rather sharp transient signal with a strong frequency component in the neighborhood of 15 kilocycles. Field strengths greater than 1 volt per meter have been detected from megaton yield weapons at a distance of about 2,000 miles. Electronic equipment which responds to rapid, short duration transients can be expected to be actuated by pickup of this electrical noise.

12.3 Thermal Damage to Various Materials

In table 12–2 the critical radiant exposures for specified damage to various materials are shown for three weapon yields. The values presented for fabrics apply for an ambient relative humidity of 65 percent and an ambient temperature of 20° C. For extremely dry conditions the values shown for fabrics should be reduced by 20 percent. For extremely high relative humidities, near 100 percent (at 20° C), the values for fabrics should be increased by 25 percent. If the fabrics are watersoaked, the critical radiant exposures should be increased by 300 percent.

Table 12-2. Critical Radiant Exposure Values for Various Materials

Uniforms	Color	Weight (oz/yd²)	Damage	Critical radiant exposure Q_c, (cal/sq cm)		
				1 KT	100 KT	10 MT
Army						
Cotton twill (fatigue)	Green	8	Scorched	3	5	9
			Destroyed	8	14	25
Wool serge (winter service)	OD	9	Scorched	3	6	10
			Destroyed	21	37	66
Wool flannel	OD	11	Scorched	3	5	8
			Destroyed	20	40	70
Wool tropical worsted	Khaki	11	Scorched	6	9	13
			Destroyed	13	20	30
Cotton twill shirt and trousers (summer)	Khaki	6	Scorched	4	6	11
			Destroyed	18	31	56
Navy						
Cotton twill (working)	Khaki	8	Scorched	3	5	8
			Destroyed	15	26	46
Cotton denim (dungaree)	Blue	9	Nap Scorched	6	10	17
			Destroyed	7	13	23
Cotton chambray shirting (working)	Blue	3	Scorched	3	6	11
			Destroyed	7	13	22
Cotton twill (white uniform)	White	8	Scorched	4	8	14
			Destroyed	34	60	109
Wool, Melton, (dress blues)	Blue	16	Scorched	1	16	13
			Destroyed	9	18	28
Wool, Kersey (overcoat)	Blue	30	Scorched	1	2	3
			Destroyed	37	65	110
Wool, serge (officer's uniform)	Blue	14	Scorched	5	9	16
			Destroyed	11	21	37
Wool, tropical worsted (officer's uniform)	Khaki	11	Scorched	5	9	16
			Destroyed	11	20	37
Vinyl resin, combined (rain)	Black	13	Scorched	1	1	2
			Destroyed	5	6	8
Marine Corps						
Cotton poplin shirting	OD	6	Scorched	3	6	10
			Destroyed	10	18	32
Wool elastique (winter)	Green	16	Scorched	2	4	7
			Destroyed	25	45	80
		21	Scorched	5	8	15
			Destroyed	30	54	95
Wool, Kersey (winter)	Green	16	Scorched	2	2	6
			Destroyed	27	48	85
Wool serge	Green	12	Scorched	2	3	6
			Destroyed	16	28	50
Air Force						
Cotton twill shirt (tropical)	Khaki	5	Scorched	6	10	19
			Destroyed	9	15	27
Wool gabardine shirt	Gray	8	Scorched	10	17	28
			Destroyed	14	22	37
Wool gabardine shirt	Blue	8	Scorched	1	2	4
			Destroyed	8	14	25
Nylon—flying jacket	OD	5	Scorched	2	3	6
			Destroyed	7	13	23

Table 12–2. Critical Radiant Exposure Values for Various Materials—Continued

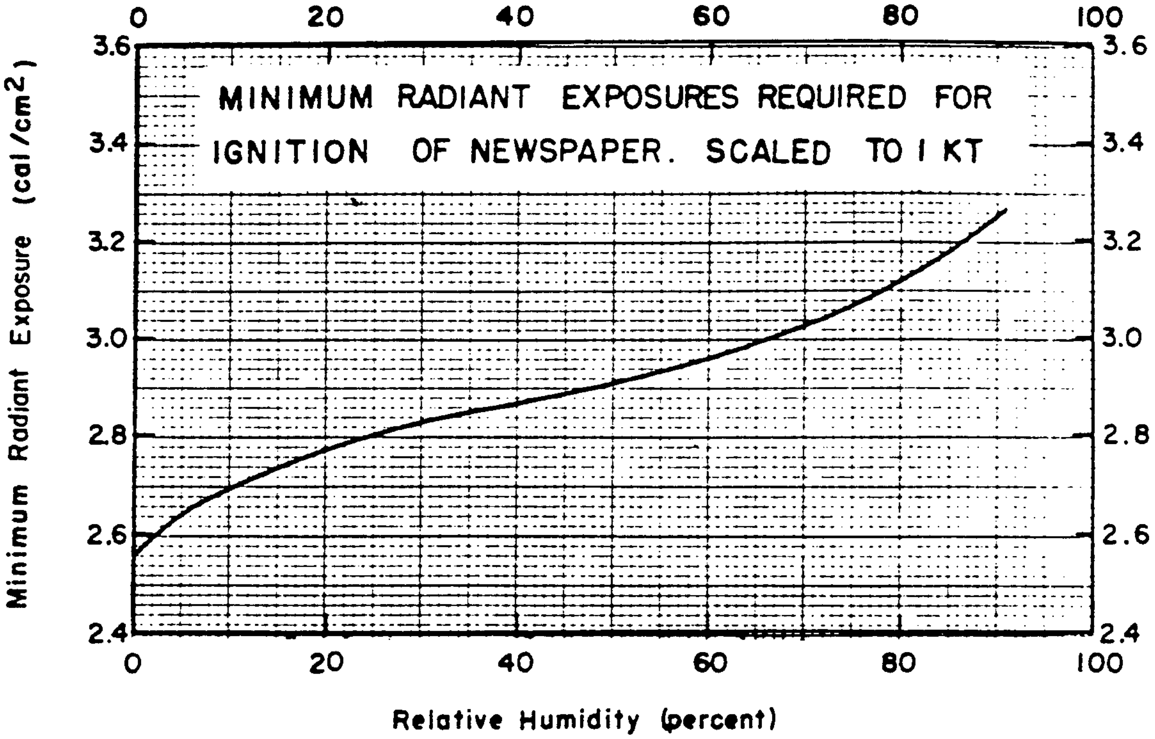
Material	Damage	Critical radiant exposure Q_c, (cal/sq cm)		
		1 KT	100 KT	10 MT
Tent material:				
Canvas, white, 12 oz/yd², untreated	Destroyed	12	21	37
Canvas, OD, 12 oz/yd², flame-proofed	Destroyed	5	9	17
Packaging materials:				
Fibreboard, V2S, BT 350 psi, laminated	Flames during exposure	9	16	29
Fibreboard, V3S, BT 275 psi, laminated	Flames during exposure	7	13	23
Fibreboard, V3C, BT 350 psi, corrugated	Flames during exposure	6	11	19
Fibreboard, W5C, BT 200 psi, corrugated	Flames during exposure	5	10	18
Plywood, douglas fir (¼ in.)	Flames during exposure	9	16	20
Airship material, aluminized, N–113A100, 16 oz/yd²	Aluminum surface discolored	20	35	61
	Aluminum surface destroyed	24	43	75
	Fabric destroyed	27	47	82
Airship material, aluminized, N–113A70, 19.4 oz/yd²	Aluminum surface discolored	10	18	31
	Aluminum surface destroyed	15	27	44
	Fabric destroyed	20	35	61
Airship material, aluminized, N–128A170, 8 oz/yd²	Delaminates	2	4	7
	Fabric destroyed	5	10	17
Doped fabrics (used on some aircraft control surfaces):				
Cellulose nitrate covered with 0.0015″ thick aluminum foil.	Sporadic flaming	60	80	140
Cellulose nitrate, aluminized	Persistent flaming	5	6	10
Plastics:				
Laminated methyl methacrylate	Surface melts	73	120	230
USAF window plastic (½ in.)	Bubbling	240	430	750
Vinylite (opaque), ⅛ in. thick	Dense smoking	3	4	6
	Flaming	20	20	25
Sand:				
Coral	Explosion*	15	27	47
Siliceous	Explosion*	11	19	35
Sandbags: Cotton canvas, dry, filled	Failure	10	18	32
Wood, white pine	0.1 mm depth char	10	18	32
White pine, given protective coating	0.1 mm depth char	40	71	126
Construction materials:				
Roll roofing, mineral surface	Surface melts	8	14	25
	Flaming during exposure	22	40	71
Roll roofing, smooth surface	Surface melts	4	7	12
	Flaming during exposure	9	16	29

*"Popcorning."

It should be emphasized that the values in table 12–2 for uniforms refer to damage to the material itself and are not applicable for predicting skin burns under uniforms.

The above discussion does not include the damage to materials when they come in contact with or are enveloped by the fireball. The heat input under these conditions is many orders of magnitude higher than the cases just discussed. Several of the variables considered as influential factors in determining the amount of surface material lost by an object exposed within a fireball include: type of material, surface curvature, orientation, thermal attenuation by the metallic vapors given off by the object, and spallation.

Figures 12–5A and 12–5B give the material loss from spheres of various materials due to ablation or scaling off of the surface material from contact with or envelopment by the fireball. Data for three types of 10-inch diameter spheres are shown; namely, solid steel, solid aluminum, and solid aluminum with small cylindrical wells filled with ceramic inserts. The one curve in figure 12–5A represents all three types.



NEWSPAPER IGNITION REQUIREMENTS

Scaling. To find minimum radiant exposures for another yield W' at the same relative humidity, multiply the exposures read from figure 12-1 by $W'^{1/8}$.

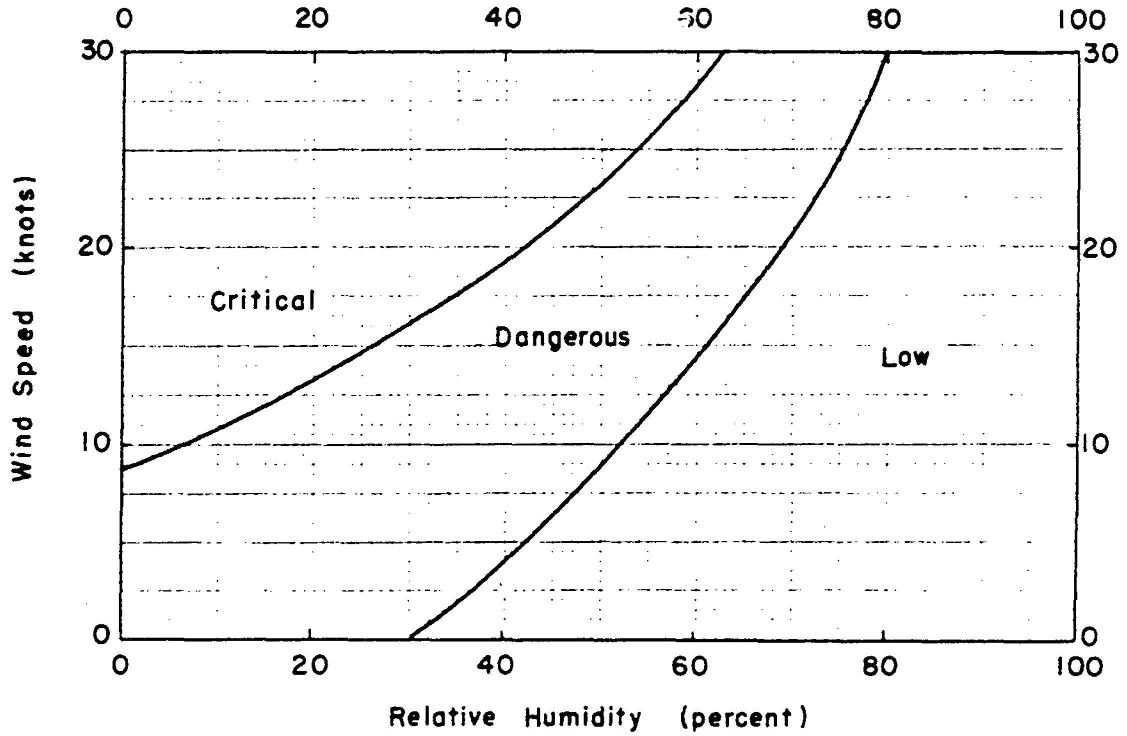
Reliability. Based upon limited empirical data.

Related material.

See paragraphs 12.1*b* and *c*.

See also figure 11-1 for radiant exposures required for wildland kindling fuel ignition.

BURNING POTENTIAL FOR URBAN AREAS
(CENTRAL HEATING NOT IN USE)



BURNING POTENTIAL FOR URBAN AREAS (CENTRAL HEATING NOT IN USE)

Figure 12-2 represents approximate values of wind speed and average daytime relative humidity conditions corresponding to low, dangerous and critical burning potentials according to the following definitions:

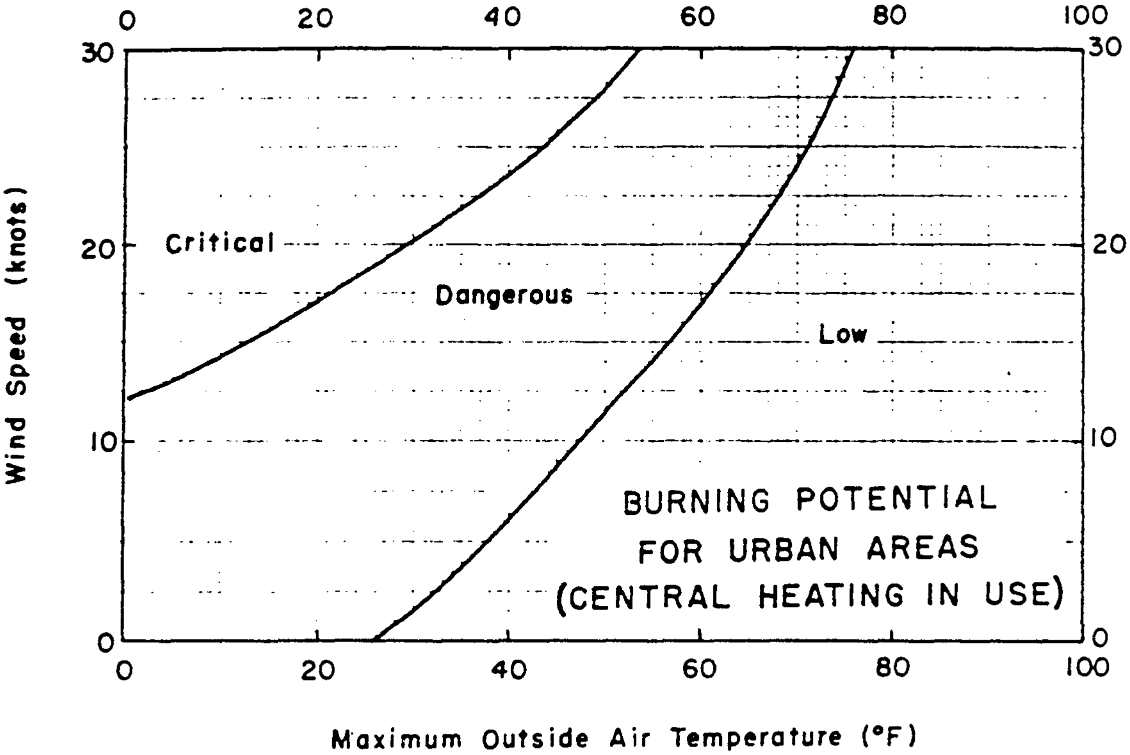
Low. Slow burning fires; fire can be controlled at will. Control action can be on unit structure basis.

Dangerous. Fires burn rapidly; individual building fires combine to form an area fire. Organized action needed to confine fire to area originally ignited.

Critical. Rapid buildup into conflagration-type fires,. high probability of fire storm, spotting frequent and severe. Requires evacuation of fire fighting equipment and personnel; control action effective only at critical breaks in building continuity or density.

Related material.

See paragraphs 12.1*c* and *d*.
See also figure 12-3.



BURNING POTENTIAL FOR URBAN AREAS (CENTRAL HEATING IN USE)

Figure 12-3 shows approximate values of wind speed and maximum outside air temperature conditions corresponding to low, dangerous and critical burning potentials. These burning potentials are defined in the same way as those in figure 12-2.

Note. Temperature must have been below value read on abscissa for at least four consecutive days, with no rain in the previous 24 hours. Snow may be disregarded.

Related material.

See paragraphs 12.1*c* and *d*.

See also figure 12-2.

NEUTRON FLUX FOR A TYPICAL FISSION WEAPON

The curves in figure 12–4 show the number of neutrons per square centimeter per kiloton at various horizontal ranges for different heights of burst of typical fission weapons. The curves are for standard atmospheric conditions. Data are presented in AFSWP–1100, published with a higher security classification, from which neutron flux for specific weapons may be computed.

Scaling. At a given horizontal range and altitude, the neutron flux is proportional to the yield of the weapon.

Example.

Given: A 100 KT air burst at 20,000 feet.

Find: The number of neutrons per square centimeter at a horizontal range of 3,400 yards.

Solution: Reading directly from figure 12–4, the neutron flux from a 1 KT weapon is 10^8 neutrons per cm^2. Since this is a 100 KT burst, 100×10^8 neutrons per cm^2= 10^{10} neutrons per square centimeter. *Answer.*

Reliability. Neutron flux is dependent upon weapon design. For most fission weapons the curves of figure 12–4 are considered reliable within a factor of 5.

FIGURE 12-4

NEUTRON FLUX FROM TYPICAL FISSION WEAPONS FOR A 1KT BURST IN A STANDARD ATMOSPHERE AS A FUNCTION OF BURST ALTITUDE AND HORIZONTAL RANGE

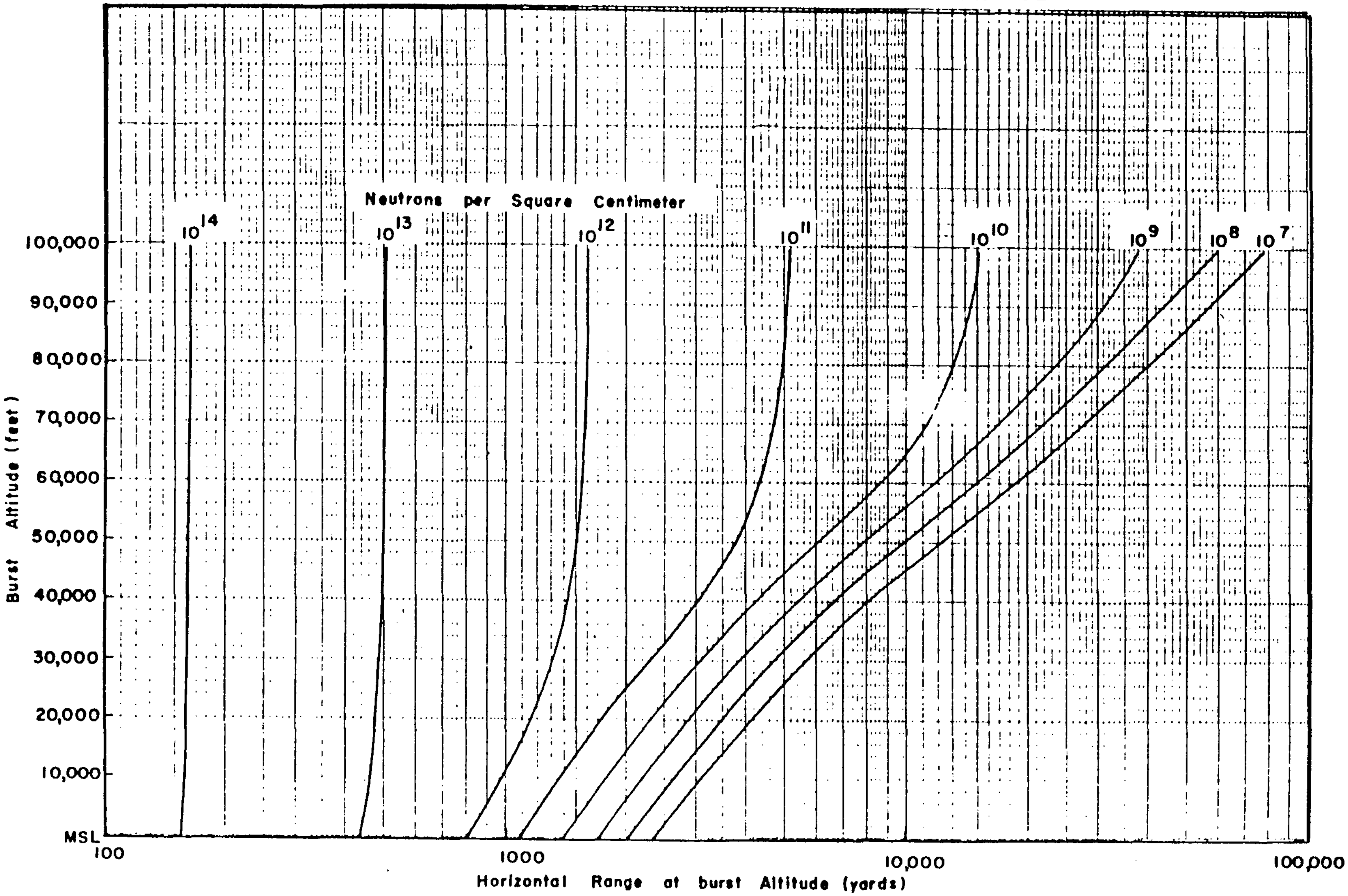
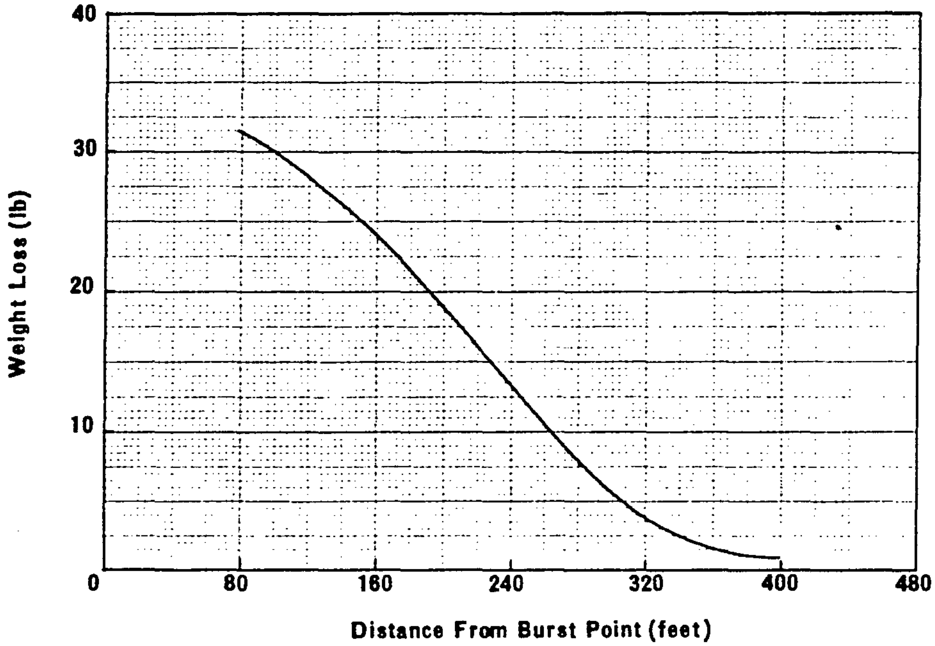


FIGURE 12-5A
FIGURE 12-5B

[redacted]

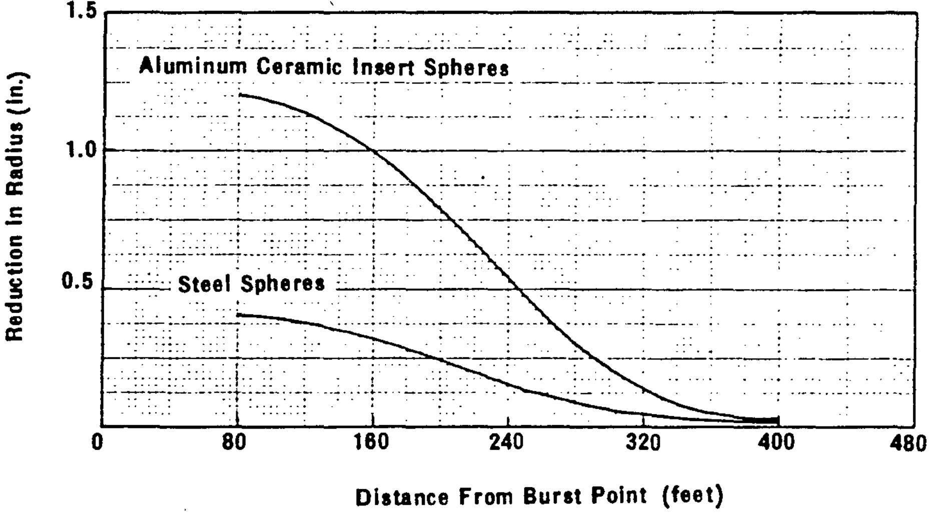
A

WEIGHT LOSS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES



B

REDUCTION OF SPHERE RADIUS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES

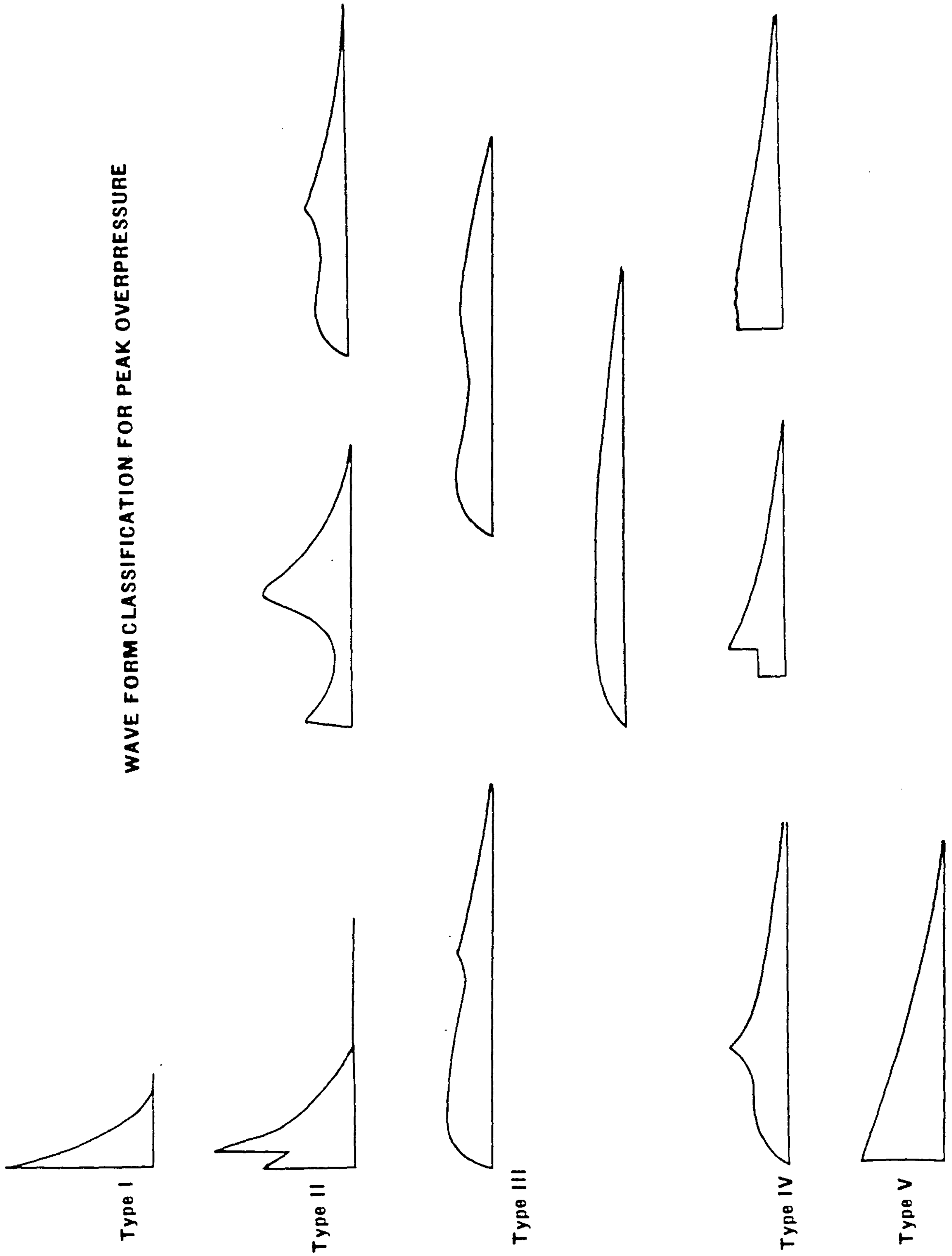


[redacted]

FIGURE I-10

~~CONFIDENTIAL~~

WAVE FORM CLASSIFICATION FOR PEAK OVERPRESSURE



~~CONFIDENTIAL~~

attenuates more rapidly than the second. At midrange, the wave form is characterized by a shock-type rise to a first low peak followed either by a plateau or a slow decay, with a longer rise to a higher second peak preceding a more rapid decay. As the ground range continues to increase, the first peak becomes round and the second peak attenuates more rapidly than the first. This wave form is typical of the early stages of development in the precursor cycle. (A detailed discussion of the precursor is given in par. 2.1*d*(4).)

Type III. A wave form whose peaks and valleys become poorly defined with increasing range. At the closer ranges the wave form shows a first large rounded maximum followed by a slow decay, then a later and smaller second peak. As the distance from ground zero increases, the first peak attenuates more rapidly than the second, so that the two peaks become comparable in magnitude, while the rise times become longer. The second peak disappears at the farther ranges, resulting in a low, rounded, flat-topped wave form with a long initial rise and a rather slow decay marked by considerable turbulence. This wave form is typical of strong precursor action.

Type IV. A wave form which progressively loses its non-classical characteristics with increasing range. At the closer ranges, the wave form shows a compression-type rise to a rounded plateau followed by a slow rise to a second higher peak. As the distance from ground zero increases, the rise times decrease, so that the front of the wave form develops a step-like appearance, and the time separation between the two peaks becomes less. At the farther ranges, the second peak overtakes the first peak to form an almost classical form with a sharp rise to a more or less level plateau, followed by an essentially regular decay. This wave form is typical of the "clean-up" portion of the precursor cycle.

Type V. A classical or ideal wave form with a sharp rise to a peak value followed by an exponential decay. The duration is rather long in comparison with the type I wave form and the rate of decay is slower.

The overpressure wave form types to be expected at a given ground range as a function of height of burst are shown in figure I–11. Since types II, III, and IV are characteristic of precursor action, the figure also delineates the precursor zone.

b. Dynamic Pressure Wave Forms. A tentative classification of the various dynamic pressure wave forms has been made. It is not possible to make a direct correlation of these with the five general types of overpressure wave forms due to the lack of experimental data for dynamic pressure, particularly in the close-in region. The classifications illustrated in figure I–12 are as follows:

Type A. A relatively ideal wave form, with a sharp rise to a peak value followed by a very rapid decay. The duration is usually rather short in comparison with later wave forms.

Type B. A double-peaked wave form with a shock-type initial rise in most cases. The second peak is larger at the closer ranges but becomes comparable in magnitude with the first as the distance from ground zero increases.

Type C. A transitional double-peaked wave form with longer initial rise time. Actual record traces have a very turbulent appearance. The second peak is smaller than the first and becomes somewhat indefinite with increasing range.

Type D. An essentially single-peaked form characterized by a low amplitude plateau with a slow, smooth rise at the closer ranges. Actual traces have a very turbulent appearance. As the distance from ground zero increases, the turbulence becomes less and the plateau develops a shock rise with a flat top or a slow steady increase to a second shock rise followed by a smooth decay. The initial disturbance at the front of the wave form eventually dies out at the farther ranges, leaving a smooth, clean record with a slight rounding after an initial shock-type rise.

Type E. A classical or ideal wave form with a sharp rise to a peak value followed by an exponential decay. The duration is rather long in comparison with type A wave forms and the rate of decay is slower.

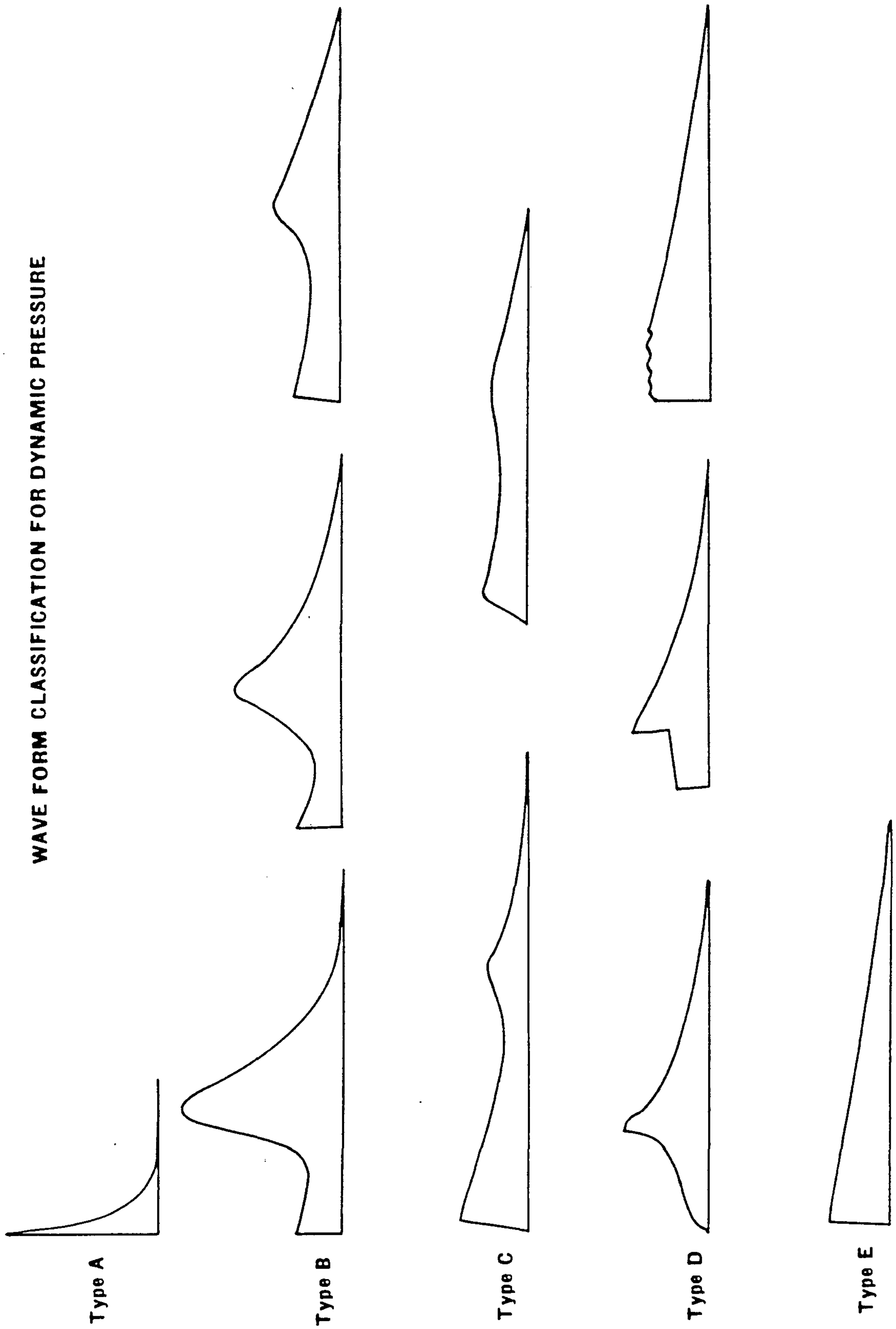
It is not possible to draw a wave form-height of burst chart for dynamic pressures at this time due to the lack of experimental data.

I.3 Altitude Conversion of Air Blast Properties

a. General. The air blast parameter curves in this manual are presented for a 1 KT burst in a homogeneous sea level atmosphere. It is sometimes necessary to determine the magnitude of

FIGURE I-12

WAVE FORM CLASSIFICATION FOR DYNAMIC PRESSURE



FREE AIR OVERPRESSURE DECAY

At a given point in space, the rate of decay of overpressure after shock front passage depends upon the peak overpressure of the shock front. Figure I-5 shows the variation in overpressure with time for various free air peak overpressures in terms of normalized coordinates; i. e., the overpressure at a given time is expressed as a fraction of the peak overpressure $\left(\frac{\Delta p(t)}{\Delta p}\right)$, and the time is expressed as a fraction of the positive phase duration $\left(\frac{t}{t^+}\right)$, where: $\Delta p(t)$ is the overpressure at the point of interest at a time t after shock front passage.

Δp is the free air peak overpressure at the point of interest, obtained from figure 2-3.

t is the time after shock front passage.

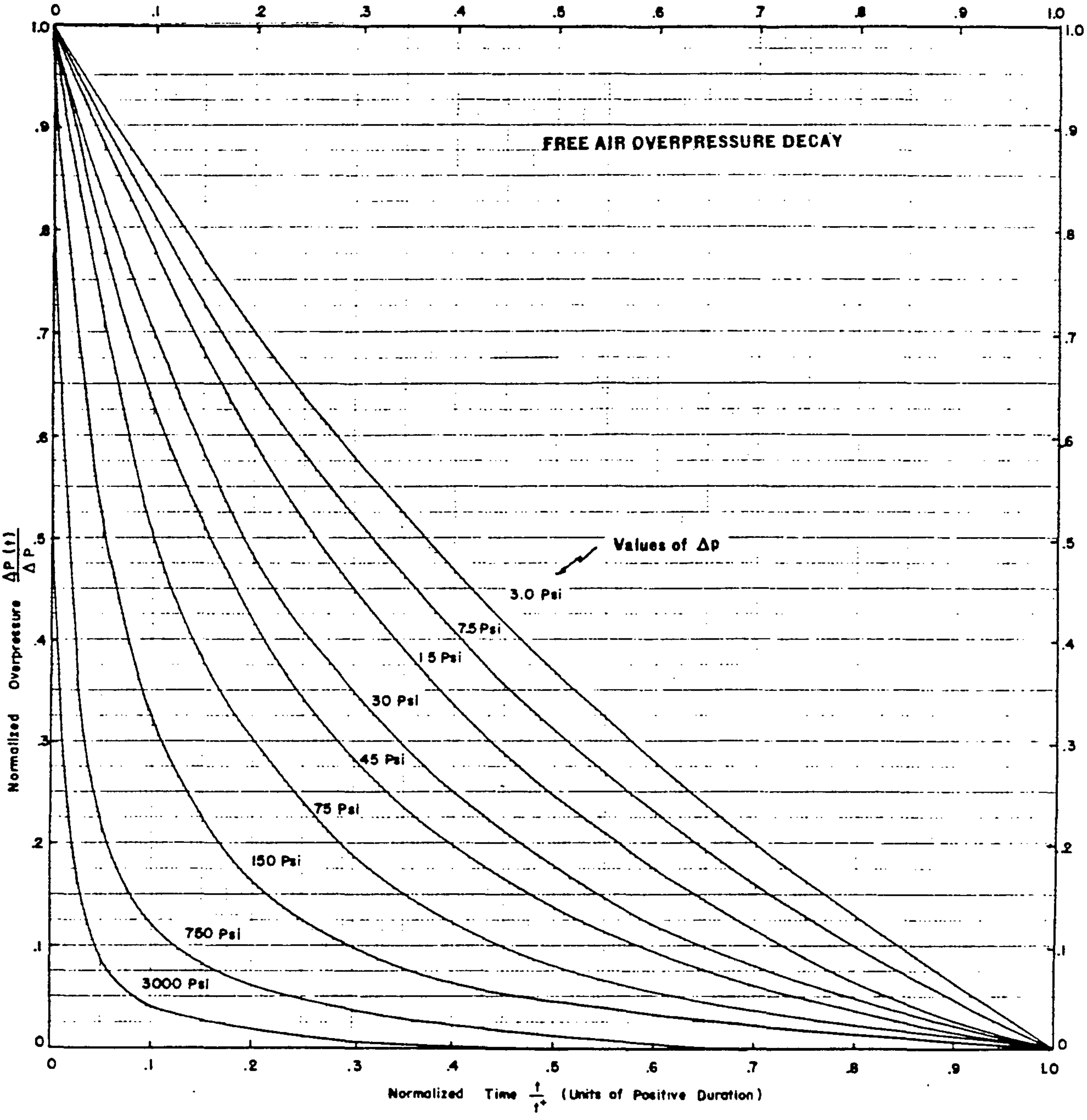
t^+ is the duration of the positive phase at the point of interest, obtained from figure 2-4.

Related Material.

See paragraph I.1*b*.

See also figures 2-1, I-6, and I-8.

FIGURE I-5


FREE AIR OVERPRESSURE DECAY
Values of Δp
3.0 Psi
7.5 Psi
15 Psi
30 Psi
45 Psi
75 Psi
150 Psi
750 Psi
3000 Psi
Normalized Overpressure $\frac{\Delta P(t)}{\Delta P}$
Normalized Time $\frac{t}{t^+}$ (Units of Positive Duration)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

FREE AIR DYNAMIC PRESSURE DECAY

At a given point in space, the rate of decay of dynamic pressure after shock front passage depends upon the peak dynamic pressure. Figure I-8 shows the variation in dynamic pressure with time for various free air peak dynamic pressures in terms of normalized coordinates; i. e., the dynamic presssure at a given time is expressed as a fraction of the peak dynamic pressure $\left(\frac{q(t)}{q}\right)$, and the time is expressed as a fraction of the positive phase duration $\left(\frac{t}{t^+}\right)$, where:

$q(t)$ is the dynamic pressure at the point of interest at a time t after shock front passage.

q is the free air peak dynamic pressure at the point of interest, obtained from figure 2-5.

t is the time after shock front passage.

t^+ is the duration of the positive phase at the point of interest, obtained from figure 2-4. The overpressure positive phase duration, t^+, is used rather than the dynamic phase duration for reasons discussed in paragraphs 2.1*b*(4)(*b*) and I.1*c*.

Related Material.

See paragraphs 2.1*b*(4)(*b*) and I.1*c*.

See also figures 2-1, I-5 and I-6.

FIGURE I-8

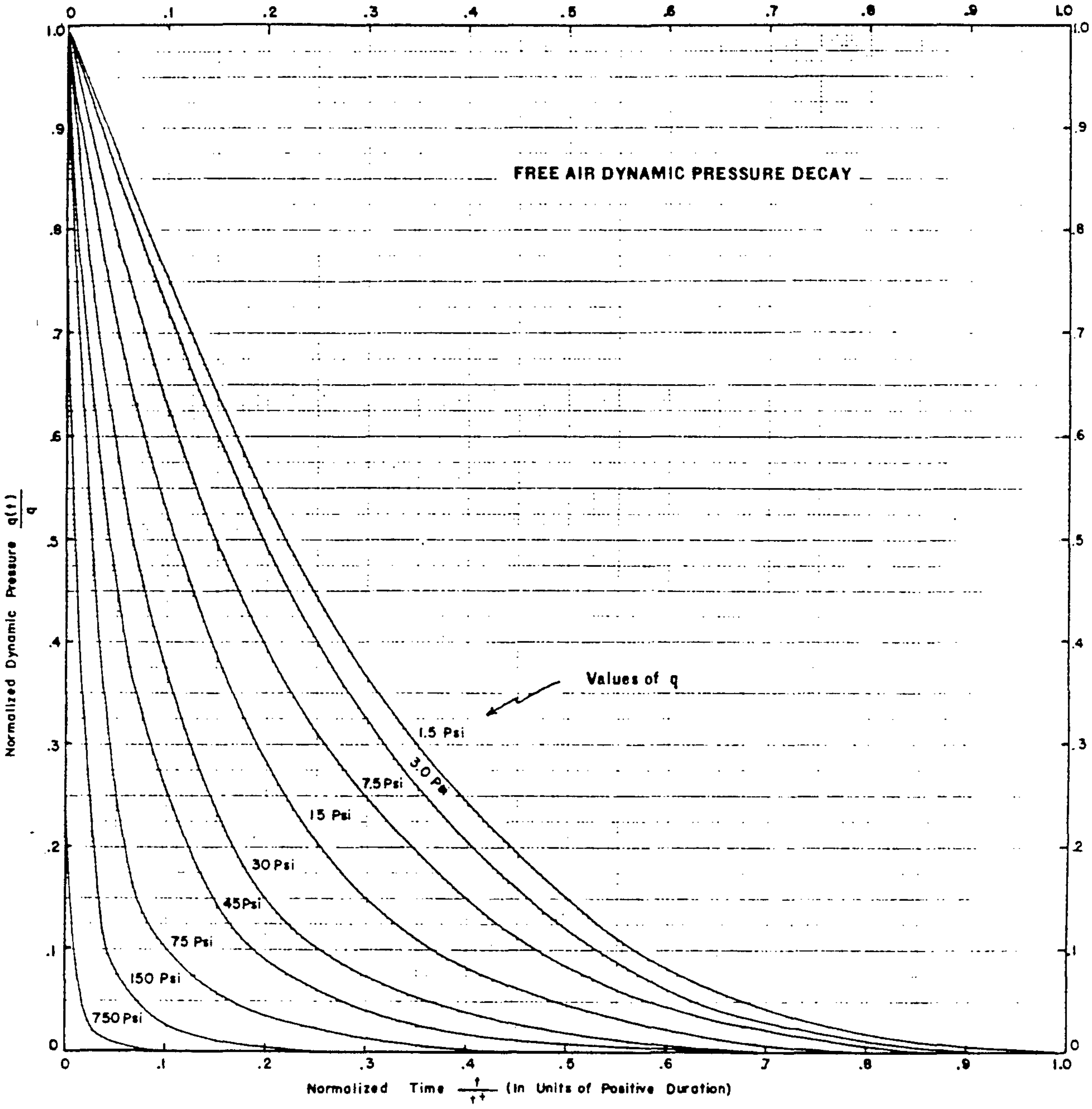
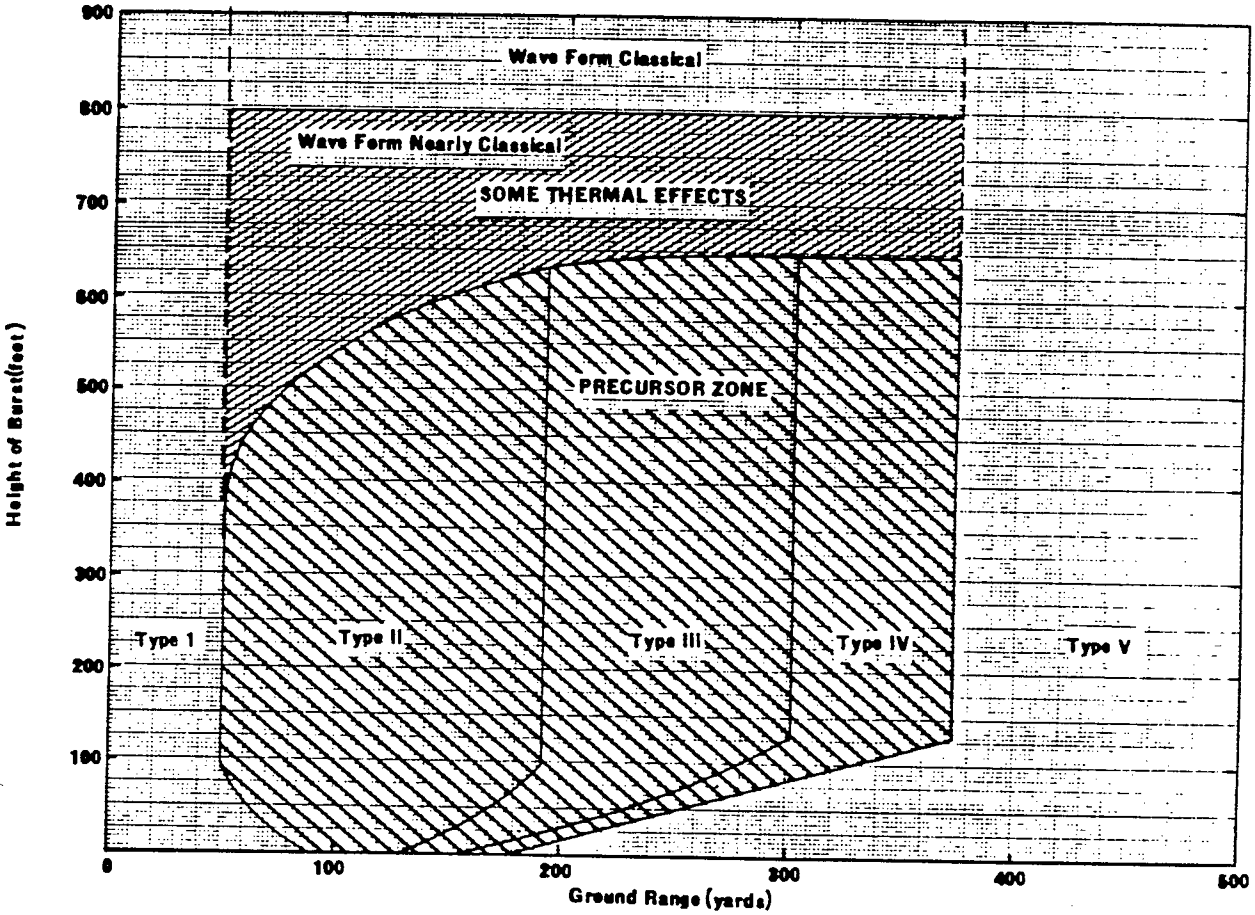

FREE AIR DYNAMIC PRESSURE DECAY
Values of q
1.5 Psi
3.0 Psi
7.5 Psi
15 Psi
30 Psi
45 Psi
75 Psi
150 Psi
750 Psi
Normalized Dynamic Pressure $\frac{q(t)}{q}$
Normalized Time $\frac{t}{t^+}$ (In Units of Positive Duration)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

FIGURE I-11

VARIATION OF OVERPRESSURE WAVE FORM WITH HEIGHT OF BURST AND GROUND RANGE FOR 1KT IN A SEA LEVEL HOMOGENEOUS ATMOSPHERE FOR AVERAGE SURFACE CONDITIONS



APPENDIX II
USEFUL RELATIONSHIPS

II.1 General

Equivalents:

1 KT is equivalent to 10^{12} calories of energy.

1 MT=1,000 KT=10^{15} calories of energy.

(Ultimately all the energy from a nuclear weapon appears as heat.)

1 KT represents about 1.5×10^{23} fissions.

Energy equivalents:

1 calorie =4.184 joules
=3.086 foot-pounds
=2.61×10^{13} Mev
=3.966×10^{-3} Btu.

186
1KT ≈ 4.2×10^{19} ergs

Mass-energy conversion: 1 gram mass=5.61×10^{26} Mev.

The temperature associated with one electron-volt is 11,605.9 degrees Kelvin.

1 millibar=1,000 dynes/cm²=0.0145 psi.

Relative air density:

Given air pressures at detonation and target altitude.

$$R=25.8\,\frac{p_1-p_2}{h_1-h_2},$$

where p_1-p_2 is pressure difference in millibars
h_1-h_2 is the altitude difference in feet

Given detonation and target at same altitude,

$$R=0.27\,\frac{p}{T}=\frac{\rho}{0.00129},$$

where p=pressure in millibars
T=absolute temperature in degrees Kelvin
ρ=air density in gm/cm.³

Given detonation and target altitude only, standard atmosphere assumed, use figure II–3.

Constants:

Velocity of light: 3×10^{8} meters per second.
Avogadro's number: 6.023×10^{23} molecules per mole.
Planck's constant: 6.624×10^{-34} joule-second
Boltzmann constant: 1.38×10^{-16} erg per degree.
Loschmidt number: 2.687×10^{19} molecules per cubic centimeter at 0° C.
Mass of electron: 9.11×10^{-28} gram.
Mass of proton: 1.67×10^{-24} gram.
Mass of alpha particle: 6.64×10^{-24} gram.
Classical electron radius: 2.82×10^{-13} cm.

Standard sea-level atmosphere:

Pressure=14.6960 lbs./square inch
=29.92 in. of mercury (at 0° C.)
=76 cm of mercury (at 0° C.)
=33.9 ft. of water (at 4° C.)
=1,013.25 millibars
=2,117 lbs./square foot
Temperature=59.000 degrees Fahrenheit
=15.000 degrees Centigrade
Density=0.0023779 slug per cubic foot
Speed of sound=1,116.215 ft/sec.

II.2 Thermal

Temperature scale conversions:

$°K=°C.+273;\ °C.=5/9\,(°F.-32)$
$°F.=9/5°C.+32;\ °R=°F.+459.4$

Thermal radiation from a nuclear weapon:

For air bursts under 50,000 feet,

$$E=\frac{W}{3}\,KT=\frac{W}{3}\times10^{12}\text{ calories }(W\text{ in }KT)$$

For surface bursts viewed from the ground,

$$E=\frac{W}{7}\,KT=\frac{W}{7}\times10^{12}\text{ calories }(W\text{ in }KT)$$

A radiant exposure of approximately 1 cal/sq cm will be received at a slant range of 1 mile from a 1 KT air burst on a clear day.

At a given slant range the radiant exposure for ground targets is proportional to weapon yield.

Time to radiant power minimum:

$$t_{\min}=\frac{W^{1/2}}{370}=0.0027\,W^{1/2}\text{ seconds }(W\text{ in }KT)$$

Time to second radiant power maximum:

$$t_{\max}=\frac{W^{1/2}}{31.2}=0.032\,W^{1/2}\text{ seconds }(W\text{ in }KT)$$

Second radiant power maximum:

For air bursts under 50,000 feet:

$$P_{max}=4\ W^{1/2}\ KT/\text{sec}=4\ W^{1/2}\times10^{12}\ \text{cal/sec}\ (W \text{ in } KT)$$

Less than 1 percent of the thermal radiation from a nuclear detonation near sea level is emitted before the radiant power minimum.

11.3. Nuclear

1 KT fission yield makes available 300 megacuries of radioactive fission product gamma activity at a time of one hour after a detonation.

1 curie is that quantity of radioactive material which undergoes 3.7×10^{10} disintegrations per second.

The roentgen is a measure of *quantity of ionization*, and is equivalent to:

83.8 ergs per gram of air; or

1.64×10^{12} ion-pairs per gram of air; or

5.24×10^{7} Mev per gram of air.

0.7 Mev is the approximate mean effective energy for the gamma rays from a residual fission product field.

To obtain the radiation intensity in roentgens per hour three feet above a plane residual fission product field, multiply the concentration of the contaminant in curies per square foot by 120, or in megacuries per square mile by 4.

Total dose in roentgens accumulated to infinite time from one hour after a burst is numerically equal to five times the dose rate in roentgens per hour at $H+1$ hour. (Fission product activity.)

The radioactive decay of gross fission products is approximately exponential with time, so that—

$$I=I_1\ t^{-1.2}$$

where I is the dose rate at any time t, and I_1 is the dose rate at unit time.

The velocity of a thermal neutron ($E=1/40$ ev) is 2,200 meters per second.

Shielding thicknesses in inches required to cut incident gamma radiation by a factor of ten are:

Material	*Initial bomb gamma*	*Residual gamma*
Lead	2.1	1.0
Iron	4.5	2.8
Concrete	18	9.5
Soil	26	14
Water	41	21

As a rough rule of thumb, the area of effect for a given degree of contamination resulting from a nuclear surface burst can be considered directly proportional to the fission yield of the weapon.

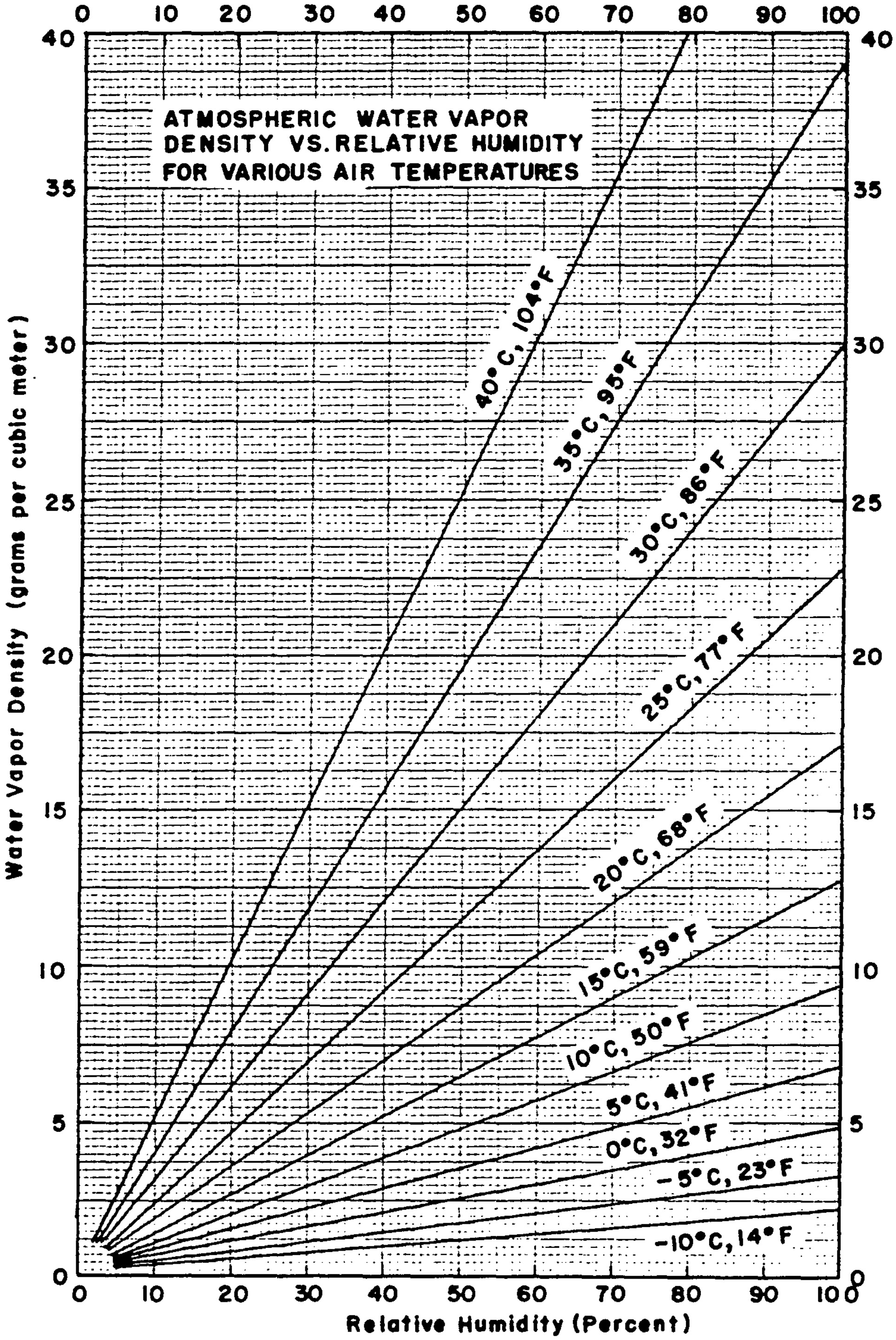
Greatest cloud diameter at 9 minutes after burst time (for kiloton yields) is approximately given by—

$$d=10{,}000\ W^{1/3}\ \text{feet}$$

The dose rate inside the bomb cloud is independent of yield (in the kiloton range) and is given by the formula,

$$D=1.31\times10^{5}t^{-2.06}\ \text{roentgens per hour,}$$

where t is the time after detonation in minutes.


ATMOSPHERIC WATER VAPOR DENSITY VS. RELATIVE HUMIDITY FOR VARIOUS AIR TEMPERATURES
Water Vapor Density (grams per cubic meter)
Relative Humidity (Percent)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
40°C, 104°F
35°C, 95°F
30°C, 86°F
25°C, 77°F
20°C, 68°F
15°C, 59°F
10°C, 50°F
5°C, 41°F
0°C, 32°F
-5°C, 23°F
-10°C, 14°F

APPENDIX IV

BIBLIOGRAPHY

This biblography contains many of the sources of data and information contained in this volume other than weapon test reports. It should not be considered inclusive, however, of all sources actually used. Many of the references listed herein contain extensive bibliographies on a particular subject. Further assistance in locating specific test data may be obtained from *Cumulative Subject Guide to Weapons Test Information*, TID 9004 (8th Rev.) (S) or the current *Abstracts of Weapon-Test Reports*, both published by Technical Information Service, Oak Ridge, Tennessee. Identification of Corporate Author Codes appears on the last page of this appendix.

GENERAL

1. *The Effects of the Atomic Bomb on Hiroshima, Japan*, Volumes I, II, III (Physical Damage Div. of U. S. Strategic Bombing Survey), May 1947 (U).
2. *The Effects of the Atomic Bomb on Nagasaki, Japan*, Volumes I, II, III (Physical Damage Div. of U. S. Strategic Bombing Survey), June 1947 (U).
3. *The Effects of Nuclear Weapons*, U. S. Govt. Printing Off., 1957 (U).

BLAST AND SHOCK PHENOMENA

1. *Airblast Peak Pressure Along the Water Surface from Shallow Underwater Explosions*, NAVORD 2571, C. R. Niffenegger (NOL), 1 Aug 52 (C).
2. *Behavior of Missiles from Underground Explosions at Dugway Covering Research from April to October 1951*, SRI-317-TR-5, R. B. Vaile, Jr. (SRI), Nov 51 (S).
3. *The Behavior of Soils Under Dynamic Loadings. III. Final Report on Laboratory Studies*, R. V. Whitman, et al. (MIT), Aug 54 (U).
4. *The Behavior of Soils Under Dynamic Loadings. IV. Review and Preliminary Correlation of Laboratory and Field Studies*, R. V. Whitman (MIT), Jun 55 (C).
5. *Blast Wave*, LA 1020–1022 (LASL), Aug 47 (S).
6. *A Comparison of Altitude Corrections for Blast Overpressures*, Haskell (AFCRC), Sep 54 (S).
7. *Comparison of the Modified Sachs Scaling with Experiments* (SC), TM 274-54-51, C. D. Broyles, 14 Dec 54 (SRD).
8. *Conference: Weather Effects on Nuclear Detonations*, AFSG 31 (AFCRC), Feb 53 (SRD).
9. *Convective Heating of Air Above an Inorganic Surface Heated by Radiation from a Nuclear Weapon*, AFSWP-862, F. M. Sauer and W. Lai (For. Serv.), Nov 55 (C).
10. *Correlation of Experimental Peak Overpressures in the Fused Shock Region*, (ARA) 236, David C. Knodel, Jan 57 (S-FRD).
11. *Crater and Slope Tests with Explosives, Part I. Testing Program and Procedure*, Memo 282-P (Panama Canal, Dept. of Op. and Main.), Jun 48 (U).
12. *Cratering from Atomic Weapons*, AFSWP-514 TAR, W. J. Christensen (AFSWP), 29 Jun 56 (SRD).
13. *Curves of Atomic Weapons Effects for Various Burst Altitudes (Sea level to 100,000 ft.)*, SC-3282 (TR), Cook and Broyles (SC), 9 Mar 54 (SRD).
14. *The Effect of Earth Cover in Protecting Structures Against Blast*, AFSWP-357, R. B. Vaile, Jr. (SRI), 30 Sep 54 (CRD).
15. *Effects of the Explosion of 45 Tons of TNT Under Water at a Depth Scaled to Test BAKER*, G. A. Young (NOL), 1 Dec 54 (S).

16. *Effects of Explosions in Shallow Water, Final Report,* (WES), Apr 55 (C).
17. *The Effect of Rain or Fog on Air Blast,* NAVORD-2944, G. K. Hartmann (NOL), 1 Aug 53 (S).
18. *Effects of Topography on Shock Waves in Air,* Condit, et al (AFSWC), TR 57-9, Aug 56 (C).
19. *Effects of Underground Explosions, Volumes I through III* (CFD/NRC), Jun 44 (U).
20. *The Effects Produced by the Explosion of Charges in Shallow Water with Particular Reference to the Atomic Bomb,* NCRE/R 43 (G. B. Naval Const. Res. Est.), Sep 48 (U).
21. *Height of Burst for Atomic Weapons,* LA-1665, F. B. Porzel (LASL), May 1954, (SRD).
22. *Height of Burst for Atomic Bombs,* LA-1406, Francis B. Porzel (LASL), Mar 52 (SRD).
23. *Height of Burst for Nuclear Weapons,* RM 1107, H. L. Brode (RAND), 1 June 54 (SRD).
24. *The Influence of Atmospheric Pressure and Temperature Variations on Shock-Wave Propagation,* AFSWP-264, NAVORD-2707, Part I—Development of Theory and Calculation of Illustrative Examples, F. Theilheimer and L. Rudlin (NOL), 7 Oct 53 (S).
25. *The Influence of Atmospheric Pressure and Temperature Variations on Shock-Wave Propagation,* Part II, AFSWP-265, L. Rudlin (NOL), 1 Aug 54 (SRD).
26. *The Interaction of Shock Waves with a Thermal Layer,* Robert Varwig and Jay Zemel (NOL), 18 Jun 55 (OUO).
27. *Underwater Explosions, A Summary of Results,* E. H. Kennard (DTMB), (C).
28. *Mach Shock Formation from a Nuclear Detonation,* AFSWP-510 TAR, R. J. Hesse and J. R. Kelso (AFSWP), 10 Mar 55 (SRD).
29. *Numerical Solution of Spherical Blast Wave,* Brode, RM 1363-AEC (RAND), 29 Sept 54 (U).
30. *On the Acoustical Theory of Transmission of a Spherical Blast Wave from Water to Air,* A. B. Arons (Woods Hole), 1956 (C).
31. *On the Oblique Reflection of Underwater Shock Waves from a Free Surface,* Parts I-IV, J. H. Rosenbaum (NOL), 1953-54 (C).
32. *Operation TEAPOT—Underground Shot Base Surge Analysis,* AFSWP-876, M. L. Milligan and G. A. Young (NOL), 31 Jan 56 (SRD).
33. *The Pelican Report: Preliminary Studies of an Underwater Atomic Explosion at Deep Submergence* (AFSWP), 10 Apr 52 (SRD).
34. *Phenomenology of a High Altitude Atomic Explosion,* SC-3363, Shelton (SC), 28 Apr 54 (SRD).
35. *The Precursor—Its Formation, Prediction and Effects,* SC-2850 (TR), Frank H. Shelton (SC), 27 Jul 53 (SRD).
36. *Prediction of Dynamic Pressure,* TM 121-54-51, R. J. Buehler (SC), 12 Jul 54 (SRD).
37. *Predictions on the Effect of Refraction on Peak Pressure and Duration of Explosion Pressure Waves,* R. R. Brockhurst (Woods Hole Oceanographic Institute), 1955 (S).
38. *Prediction of Incident Pressure-Time Curves for Nuclear Explosions,* SC-5112 (82), Luke J. Vortman (SC), Jan 54 (SRD).
39. *A Preliminary Estimate of the Effect of Fog and Rain on the Peak Shock Pressure from an Atomic Bomb,* AFCRD AFSG-16, H. P. Gauvin and J. H. Healy (AFCRC), Sep 52 (SRD).
40. *The Preshock Sound Velocity Field over Inorganic and Organic Surfaces,* AFSWP-420, F. M. Sauer (For. Serv.), Dec 54 (C).
41. *Rain, Fog and Cloud Effects on Blast Damage from Atomic Weapons,* SC-3008 (TR), Thomas B. Cook (SC), 22 Oct 53 (SRD).
42. *Refraction and Diffraction of Explosion Pressure Pulses by Gradients in the Propagation Velocity,* R. R. Brockhurst (Woods Hole), 1957 (C).
43. *Response of Non-Linearly Supported Boundaries to Shock Waves, Case of the Spherical Cavity,* M. L. Baron (Col. U.), Mar 56 (C).
44. *A Scale Model Study of the Effects of Symmetric Ridges on Blast Overpressures,* SC-3335 (TR), J. Todd (SC), 3 May 54 (C).

45. *The Scaling of Base Surge Phenomena of Shallow Underwater Explosions*, AFSWP–484, M. L. Milligan and G. A. Young (NOL), 1 May 54 (C).
46. *Shock Wave Diffraction*, N7onr–32104, Sachs and Sauer (SRI), (SRD).
47. *Small Explosion Tests*, Project MOLE, Volumes I and II, D. C. Sachs and L. M. Swift (SRI), Dec 55 (SRD).
48. *Spherical Wave Propagation in Water*, Part I, S. C. Lowell (NYU), Oct 55 (U).
49. *Study of Blast Effects in the Regular Reflection Region*, Task VI, Phase Report No. III of Ad Hoc Analytical Services, ARF–MO44-Phase II (ARF), 4 May 54 (S).
50. *Study of Underwater Blast*, F. B. Porzel (ARF), 1956 (CRD).
51. *Theoretical Blast Wave Curves for Cast TNT*, OSRD–5481, J. G. Kirkwood and S. R. Brinkley, Jr. (OSRD), Aug 45 (U).
52. *Underground Explosion Test Program*, Final Report, Volume I—"Soil," Volume II—"Rock" (ERA), 30 Apr 52 (C).
53. *Underwater Explosions*, R. H. Cole (Princeton U. P.), 1948 (U).
54. *Water Waves Produced by Explosions*, H. C. Kranzer and J. B. Keller (NYU), Sep 55 (U).
55. *Wave Propagation in Solids*, Edmund Pinney (Calif. U.), Jan 55 (U).

THERMAL RADIATION PHENOMENA

1. *Airborne Thermal Radiation Measurements at Operation CASTLE*, USNRDL–TR–87, R. P. Day, A. Guthrie, and W. B. Plum (NRDL), 17 May 56 (SRD).
2. *Airborne Thermal Radiation Measurements at Operation IVY*, USNRDL–412, T. R. Broida and A. Broida (NRDL), 14 Aug 53 (SRD).
3. *Atmospheric Attenuation of Thermal Radiation from a Nuclear Detonation*, AFSWP–509, L. B. Streets and Harvey Marron (AFSWP), Dec 1, 54 (C).
4. *Attenuation of Thermal Radiation by a Dispersion of Oil Particles*, AFSWP–749, C. M. Sliepcevich, et al. (ERI), May 54 (C).
5. *Basic Characteristics of Thermal Radiation from an Atomic Detonation*, AFSWP–503 TAR, L. B. Streets (AFSWP), Nov 53 (SRD).
6. *High Altitude Effects on Blast-Thermal Partition of Energy from Nuclear Explosions, and Associated Scaling Laws*, SC–2969 (TR), F. H. Shelton (SC), 15 Sep 53 (SRD).
7. *Horizontal Attenuation of Ultraviolet and Visible Light by the Lower Atmosphere*, NRL 4031, Lawrence Dunkelman (NRL), 10 Sep 52 (U).
8. *Infrared Transmission of Blackbody Radiation through the Atmosphere* (AFCRC–TN–55–857), D. Burch and J. N. Howard (Ohio St. U.), May 55 (U).
9. *Reflected Radiation from an Infinite Lambert Plane*, NRL Memo–122, William B. Fussell (NRL), Jan 53 (U).
10. *Reflection of ABD Thermal Radiation by a Diffusing Ground Surface*, Part 28, NML 5046–3 (NY Naval Shipyard, ML), 5 Nov 53 (C).
11. *Reflections of Radiant Energy from Perfectly Diffusing Surfaces to Horizontal, Flat Targets*, AFSWP-513 TAR, H. Marron and L. B. Streets (AFSWP), 1 Dec 55 (U).
12. *Reflection of Radiation from an Infinite Plane*, Part I, DR–1434, Ralph Zirkand (DN BuAer), Jun 53 (U).
13. *Scaling of Thermal Radiation from Nuclear Detonations*, AFSWP–795, A. Broida (NRDL), 10 Mar 54 (SRD).
14. *Spectral and Radiometric Comparisons of Wasp and HA*, NRL Rpt 4555 RD 538 (NRL), May 1955 (SRD).
15. *A Study of the Effects of Environment on Thermal Radiation*, AFSWP–601, L. B. Streets (AFSWP), Jun 53 (C).

16. *Thermal Data Handbook*, AFSWP-700 (TOI), 1 Nov 54 (SRD).
17. *Total Transmission of the Atmosphere in the Near-Infrared*, NRL 3858, Harold Yates (NRL), 10 Sep 51 (U).

NUCLEAR RADIATION PHENOMENA

1. *Contamination Patterns at Operation JANGLE*, USNRDL-399, R. K. Laurino and I. G. Poppoff (NRDL), 30 Apr 53 (SRD).
2. *The Effects of Soil, Yield, and Scaled Depth on Contamination from Atomic Bombs*, R. D. Cadle (SRI), 29 Jun 53 (SRD).
3. *An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products*, AD-95 (H), R. I. Condit, J. P. Dyson, and W. A. S. Lamb (NRDL), Apr 49 (C).
4. *Delayed Gamma-Rays from Uranium Photofission*, AFSWP-991, J. M. Wyckoff and H. W. Koch (NBS), 30 Sep 55 (U).
5. *Evaluation of Radioactive Fall-Out*, AFSWP-978, R. D. Maxwell (AFSWP), 15 Sep 55 (SRD).
6. *Fall-Out Symposium*, AFSWP-895 (AFSWP), Jan 55 (SRD).
7. *The Fast Neutron Hazard*, Titus C. Evans, Nucleonics 4:3, Mar 49 (U).
8. *Gamma Radiation in Air Due to Cloud or Ground Contamination*, AFSWP-465, M. J. Berger and J. A. Doggett (NBS), 1 Jun 53 (U).
9. *Gamma-Ray Spectral Measurements of Fall-Out Samples from Operation CASTLE*, AFSWP-822, C. S. Cook (NRDL), 26 Jan 55 (SRD).
10. *Hazard Due to Beta Radiation from Fission Products Deposited on the Ground After an Atomic Explosion*, CREL-529, F. S. Goulding and G. Cowper, Atomic Energy Commission of Canada, Ltd., Jan 53 (U).
11. *Interim Report on the NDA-NBS Calculation of Gamma Ray Penetration*, NDA Memo 15c-20, H. Goldstein, et al. (NDAI), 8 Sep 53 (U).
12. *Investigation of Gamma Radiation Hazards Incident to an Underwater Atomic Explosion*, W. E. Strope (BuShips, DN), 1948 (C).
13. *The Nature of Individual Radioactive Particles. I. Surface and Underground ABD Particles from Operation JANGLE*, USNRDL-374, C. E. Adams, I. G. Poppoff, and N. R. Wallace (NRDL), 28 Nov 52 (S).
14. *Radioactive Fall-Out Hazards from Surface Bursts of Very High Yield Nuclear Weapons*, AFSWP-507, D. C. Borg, L. D. Gates, T. A. Gibson, Jr., and R. W. Paine, Jr. (AFSWP), May 54 (SRD).
15. *The Relative Importance of Nuclear Radiation from Atomic Weapons Detonated at High Altitudes*, AFSWP-500, P. W. Ifland (AFSWP), 1953 (SRD).
16. *The Residual Radiological Hazard from the Air Detonation of an Atomic Weapon in the Rain*, AFSWP-501, L. D. Gates, et al. (AFSWP), May 53 (SRD).
17. *Scaling of Contamination Patterns, Surface and Underground Detonations*, NRDL-TR-1, C. F. Ksanda, et al. (USNRDL), Sep 53 (SRD).
18. *Spectral Distribution of Gamma Rays Propagated in Air*, AFSWP-502A, L. D. Gates and C. Eisenhauer (AFSWP), Jan 54 (U).
19. *Spectrum and Attenuation of Initial Gamma Radiation from Nuclear Weapons*, AFSWP-502B TAR, D. C. Borg and C. Eisenhauer (AFSWP), Jan 55 (SRD).
20. *Studies on the Propagation of Gamma Rays in Air, June 30–October 15, 1953. Final Progress Report*, AFSWP-449, W. Bernstein, et al. (BNL), 1953 (U).
21. *Survey of Data on Residual Gamma Spectra*, AFSWP-427, S. Miller, et al. (NBS), 30 Jul 54 (C).
22. *Transport and Early Deposition of Radioactive Debris from Atomic Explosions*, S. M. Greenfield, W. W. Kellogg, F. J. Krieger, R. R. Rapp (RAND), Jul 54 (SRD).
23. *Nuclear Radiation Handbook*, AFSWP-1100 (NDA), Mar 25, 1957 (SRD).
24. *Prediction of Neutron-Induced Activity in Soils*, AFSWP-518, J. F. Canu and P. J. Dolan (AFSWP), 11 Jun 57 (SRD).

PERSONNEL CASUALTIES

1. *The Acute Radiation Syndrome, A Study of Ten Cases*, LA–1095–1097, Hempleman (LASL), Mar 50 (OUO).
2. *Biological Effectiveness of Nuclear Radiation from Fission Weapons*, LA–1987, Payne S. Harris (LASL), Aug 55 (SRD).
3. *The Biological Effects of Blast*, TID–5251, C. S. White (AEC), 15 Sep 54 (SRD).
4. *The Burn Problem in Atomic Warfare*, E. I. Evans, Journal of the American Medical Association, CXLIII, 1143, 1950 (U).
5. *The Effects of Blast Phenomena on Man: A Critical Review* (CHABA–3), Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics, Jun 55 (U).
6. *The Combined Effects of Thermal Burns and Whole-Body X-Irradiation on Survival Time and Mortality*, AFSWP–470, and 473, 474, 475, E. L. Alpen, et al. (NRDL), May, Oct, 53 (U).
7. *The Dose Received by Partially Shielded Gamma Ray Detectors*, AFSWP–466, M. J. Berger (NBS), 8 Oct 54 (U).
8. *The Effect of Atomic Explosions in Causing Temporary Blindness*, ORO–T–115, J. Green (ORO/JHU), 28 Sep 50 (U).
9. *Effect of Nuclear Weapon Yield on Effectiveness of Thermal Energy for Burn Production*, AFSWP–734, E. L. Alpen (NRDL), 30 Aug 54 (SRD).
10. *Effects of Spectral Distribution of Radiant Energy of Cutaneous Burn Production in Man and Rat*, AFSWP–737, E. L. Alpen, et al. (NRDL), 25 Apr 55 (U).
11. *The Effects of Total-Body Fast Neutron Irradiation in Dogs*, AFSWP–760, V. P. Bond, et al. (NRDL), 10 Jan 55 (U).
12. *Experimental Work on Physiological Effects of Blast*, RC–108, S. Zuckerman (G. B., Ministry of Home Sec.), June 40 (S).
13. *Exposure of Monkeys to High Doses of Fission Neutrons from Godiva*, LA–1838, W. H. Langham, et al. (LASL), Oct 54 (SRD).
14. *Extension to Man of Experimental Whole Body Radiation Studies*, Vol. 112, F. C. McLean, J. H. Rust, A. M. Budy, Military Surgeon, Mar 53 (U).
15. *Heat-Reflecting Textiles as Protective Barriers Against Intense Thermal Radiation*, AFSWP–849, R. C. Maggio and T. B. Gilhooly (NML), 25 Mar 55 (U).
16. *Maximum Permissible Amounts of Radioisotopes in the Human Body*, Handbook 52 (NBS), 20 Mar 53.
17. *Mechanical and Thermal Injury from the Atomic Bomb*, E. H. Pearse and J. T. Payne (NEJM, CCXLI, 647), 1949 (U).
18. *Ocular Lesions Following the Atomic Bombing of Hiroshima and Nagasaki*, MDDC 936, J. J. Flick (AEC Oak Ridge, Tenn.), 13 May 47 (U).
19. *Pathologic Effects of Atomic Radiation*, NAS–NRC 452, 1956 (U).
20. *Permissible Doses from External Sources of Ionizing Radiation*, Handbook 59 (NBS), 24 Sep 54.
21. *Reflectance and Absorptance of Human Skin*, AFSWP–840, W. Derksen (NML), 31 Mar 55 (U).
22. *The Relative Biological Efficiency of Different Ionizing Radiations*, AFSWP–436, John W. Boag (NBS), 30 Dec 53 (U).
23. *The Relative Biological Effectiveness of Fast Neutrons in Mice*, AFSWP–759, R. E. Carter, et al. (NRDL), 17 Nov 54 (U).
24. *Report of the International Committee on Radiological Units and Measurements*, Handbook 62 (NBS), 10 Apr 57.
25. *Report on the Medical Studies of the Effects of the Atomic Bomb*, M. Tsuzuki (Gen. Rpt., Atomic Bomb Casualty Commission, Washington National Research Council, App. 9), 1947 (U).
26. *Research Report on the Accuracy With Which Flash Burns May Be Predicted From the Temperature History of a Skin Stimulant*, AFSWP–953, W. L. Derksen (NML), 19 Jun 56 (U).

27. *Research Report on the Influence of Air Supply and Air Flow on Burns Behind Irradiated Fabrics*, AFSWP-1000, W. L. Derksen and J. J. Bates (NML) (U).
28. *Studies of the Effects of Massive, Rapid Doses of Gamma Rays on Mammals*, LA-1643, W. H. Langham, et al. (LASL), 1953 (U).
29. *A Study of Radiant Energy Burns: The Effect of Exposure Time and Intensity*, UR-217, J. B. Perkins, H. E. Pearse, and H. D. Kingsley (Univ. of Rochester A. E. Proj. Rpt.), 1952 (U).
30. *Thermal and Combined Thermal and Ionizing Radiation, Effects on Biological Systems*, AFSWP-471, 475 and 735, E. L. Alpen (NRDL), 1953–1954.

DAMAGE TO STRUCTURES

1. *Air Blast Loading on a Scaled Three-Dimensional Structure*, AFSWP-813, C. N. Kingery and J. H. Keefer (BRL), Jul 55 (U).
2. *Air Blast Loading Test on Structures*, Operation DRAGON, Int. Rpt. SRI-P-678 Int. 3, S. R. Hornig and D. C. Sachs (SRI), Jul 54 (C).
3. *Air Blast Loading on Three-Dimensional Scale Models of Dome Shape*, AFSWP-773, E. Rines, et al. (BRL), Apr 55 (U).
4. *Analysis of Gravity Dams Subjected to Underwater Explosions*, Int. Rpt., C. H. Norris (MIT), 1 Jul 53 (S).
5. *Behavior of Reinforced Concrete Structural Elements Under Long Duration Impulsive Loads*, Part I. Summ. Rpt., MIT-25A, Robert J. Hansen (MIT), Sep 49 (U).
6. *Behavior of Truss Bridges Under Blast From an Atomic Bomb, Phase I and II*, MIT 29 and MIT 29A, J. S. Archer, W. B. Delano and S. Namyet (MIT), 1950–51, Phase I (C); Phase II (OUO).
7. *Blast Loading End Effects I*, AFSWP-461, C. C. Hudson (SC), 24 Aug 54 (C).
8. *Blast Pressure Requirements for Structural Damage*, AFSWP-805, N. M. Newmark (Ill. Univ.), Aug 54 (S).
9. *Deformation Model Studies of Buildings Subjected to Blast Loading*, AFSWP-166 (Stan. U. VRL TR-20), H. A. Williams and A. K. Ruby (Stan. U.), 1 Dec 54 (U).
10. *Deformation Model Analysis of Building 2, Army Test Structure, Operation GREENHOUSE*, AFSWP-167 (Stan. U. VRL TR-21), Harry A. Williams (Stan. U.), 15 Dec 54 (C).
11. *Design of Structures to Resist the Effects of Atomic Weapons*, EM-1110-34 (MIT) (U).
12. *Diffraction of a Mach Stem Shock over a Square Block*, AFSWP-704, E. B. Turner, et al. (ERI), Jan 56 (U).
13. *Dynamic Analysis of a One Story Rigid Frame*, AFSWP-605, R. C. DeHart (AFSWP), 29 Sep 55 (U).
14. *The Effect of Blast Loading Duration on Structural Damage*, AFSWP-508 TAR, S. B. Smith, et al. (AFSWP), May 54 (S).
15. *The Effect of Earth Cover in Protecting Structures Against Blast*, AFSWP-357A, R. B. Vaile, Jr. (SRI), 30 Sep 54 (CRD).
16. *The Effects of Surface Roughness*, AFSWP-990, G. Naguma and A. H. Wiedermann (ARF), Dec 55 (C).
17. *An Engineering Approach to Blast Resistant Design*, N. M. Newmark (Proceedings American Society of Civil Engineers), Separate No. 306, Oct 53 (U).
18. *Field Fortifications Test, Exercise Desert Rock VI*, Technical Rpt. 1468-TR (ERDL), 2 Nov 56 (SRD).
19. *Investigation of Shear Walls*, Parts I and II (U), III through V (C), Williams and Benjamin (Stan. U.), 1952–53.
20. *Load Deformation Characteristics of Simulated Beam Column Connections in Reinforced Concrete*, AFSWP-174 (Ill. U. SRS-76), R. M. McCollister, et al. (U. of Ill.), Jun 54 (U).
21. *Loading Analysis of Five Story Reinforced Concrete Frame Structures* (in the Regular Reflection Region, Two-Dimensional), (ARF), 16 Jul 56 (C).
22. *Methods for Estimating Blast Loading on Simple Structures*, AFSWP-226, Vortman, L. J., Merritt, M. L. (SC), Sep 53 (SRD).

23. *On the Effect of Slow Rise Times on the Blast Loading of Structures*, AFSWP-4[illegible], M. L. Merritt (SC), 25 Sep 53 (CRD).
24. *Response of a Single Story Heavy Steel Frame Industrial Building to Atomic Blast*, AFSWP-782, A. Finerman and J. H. King (MIT), Dec 55 (S).
25. *Self-Shielding from Blast Waves by Structural Members*, AFSWP-225, C. C. Hudson (SC), May 53 (U).
26. *Shielding of Three-Dimensional Blocks*, AFSWP-989 (ARF), Nov 55 (C).
27. *A Simple Method for Evaluating Blast Effects on Buildings*, ARF-EMR-1 (ARF), Jul 52 (U).
28. *Study of Atomic Blast Damage to Buildings at Hiroshima and Nagasaki*, AFSWP-808, J. S. Archer (MIT), Jul 54 (C).
29. *The Theoretical Elastic Response of Shear Walls Subjected to Dynamic Loads*, AFSWP-818, A. Finerman (MIT), Aug 56 (U).

DAMAGE TO NAVAL EQUIPMENT

1. *Model Studies on Effects of Underwater Atomic Explosions on Ships*, Parts I–V, W. W. Murray (UERD), 1957 (C).
2. *On the Prediction of the Hull Splitting Standoff of Submarines from Atomic Depth Charges*, A. H. Keil and H. M. Schauer (UERD), 1956 (C).
3. *Proceedings of Seventh Symposium on Underwater Explosion Research*, Parts I (C) and II (DTMB), 1956 (SRD).
4. *Submarine Lethality Curves for Underwater Atomic Explosions*, D. S. Cohen (UERD), 1956 (C).
5. *Underwater Explosion Research, Vol. III*, (ONR Compendium) (U).

DAMAGE TO AIRCRAFT

1. *The Effects of Atomic Explosions on Aircraft*, 7 Volumes, WADC TR 52-244 (MIT), 1953 (SRD).
2. *General Design Considerations for Aircraft Operating in the Vicinity of a Nuclear Burst*, WADC TR-53-238, David J. Fink (WADC), Jul 53 (SRD).
3. *Résumé of the Effects of Very High Yield Atomic Explosions on Aircraft Structures—Explosion Characteristics, Structural and Aeroelastic Blast Effects, and Thermal Radiation Effects*, WADC Tech. Rpt. 54-386, E. A. Witmer, et al. (WADC), 10 Aug 56 (SRD).
4. *Three-Dimensional Lethal Envelopes for the B-52 at 35,000-foot and 45,000-foot Altitudes Subjected to 2.0 KT and 0.5 KT Atomic Bursts* (C), ARA-185, D. J. Fink, P. B. Athens, (ARA), 18 Aug 54 (SRD).
5. *The Vulnerability of the MIG-17 (FRESCO) to Free-Air Nuclear Detonations*, ARA-220, D. J. Fink, et al. (ARA), 10 Jun 55 (SRD).
6. *The Vulnerability of Parked Army Aircraft to Nuclear Detonations*, WADC Tech. Rpt. 56-354, D. H. Whitford (WADC), Jun 56 (SRD).

DAMAGE TO MILITARY FIELD EQUIPMENT

1. *The Effects of Atomic Weapons on Engineer Heavy Equipment*, ERDL-1443 (ERDL), 25 Apr 56 (U).
2. *Exercise Desert Rock I* (Hq III Corps, Ft McArthur), Oct 51 (SRD).
3. *Report of Test Exercises Desert Rock II and III* (Hq Camp Desert Rock), 15 Dec 51 (SRD).
4. *Exercise Desert Rock IV* (Hq Sixth Army), Apr–Jun 1956 (SRD).
5. *Exercise Desert Rock V* (Hq Camp Desert Rock), Jan–Jun 53 (SRD).
6. *Analysis of Atomic Weapons Effects Upon Army Ground Operations Equipment*, ORO Repts., Phases I through V, Dec 50–Jul 52 (S).
7. *Damage to Field Military Equipment from Nuclear Detonations*, AFSWP-511 TAR, R. J. Hesse (AFSWP), 1 Feb 56 (SRD).
8. *The Influence of Atomic Weapons on Signal Communications in an Infantry Division* (SigC Board Study No. 93A), 14 Jan 53 (S).

9. *Influence of Atomic Weapons on Signal Communications in Corps and Army Areas* (SigC Board Study No. 95), 2 Apr 52 (S).
10. *Studies of Railroad Marshalling Yards,* ARF Project No. M055 (Final Report) (ARF) (C).

FOREST STANDS

1. *Burning Potential—Forest and Wildland Areas,* Phase Rpt. 1/52, Keith Arnold, et al. (For. Serv.), Jan 52 (C).
2. *Comparison of Field and Laboratory Forest Fuel Ignition Energies and Extrapolation to High-Yield Weapons,* AFSWP–870, F. M. Sauer (For. Serv.), Mar 56 (SRD).
3. *A Study of the Influences of a Forest on the Effects of an Atomic Weapon,* AFSWP–602, L. B. Streets (AFSWP), Jun 53 (C).
4. *Thermal Conductivity of Some Common Forest Fuels,* AFSWP–405, G. M. Byram, et al. (For. Serv.), 1 Dec 52 (U).
5. *Thermal Properties of Forest Fuels,* AFSWP–404, G. M. Byram, et al. (For. Serv.), Oct 52 (U).
6. *Blast Effects on Forest Stands by Nuclear Weapons,* AFSWP–971, W. L. Fons, F. M. Sauer, and W. Y. Pong (For. Serv.), 1957 (C).

MISCELLANEOUS RADIATION DAMAGE CRITERIA

1. *Apparatus and Methods for the Exposure of Materials to Thermal Radiation,* AFSWP–246, G. E. Davis (NML), 2 Oct 52 (U).
2. *Critical Thermal Energies of Construction Materials,* AFSWP–839, L. Banet and J. Bracciaventi (NML), 30 Dec 54 (U).
3. *Distribution of Primary Ignition Points Following Atomic Attack on Urban Targets-Transient Exterior Fuels,* AFSWP–412, G. C. Chandler and Keith Arnold (For. Serv.), Mar 53 (U).
4. *Effects of Thermal Radiation on Materials, Final Report On,* A. F. Robertson (NBS), 1 Nov 53 (C).
5. *Frequency of Urban Building Fires as Related to Daily Weather Conditions,* AFSWP–866, A. R. Pirsko (For. Serv.), Mar 56 (U).
6. *Investigation of Optical Transmittance, Reflectance, and Absorptance of Materials,* AFSWP–396, R. F. Byrne and L. N. Mancinelli (NML), 12 Mar 54 (U).
7. *A Method for Estimating Probable Ignitions of Interior Fuels by Atomic Weapon Explosion (Survey of Boston and Detroit),* AFSWP–340, H. D. Bruce and L. E. Downs (Forest Products Lab), 1 Feb 56 (SRD).
8. NML Reports on Critical Thermal Energies of Various Specific Materials as follows:

   Metallized rayon fabric, AFSWP–390; Doped fabrics, AFSWP–389, 388, 244, 393; Aluminized fabrics, 384; Protective coatings on wood, 382; Awning material, 381; Aluminized asbestos cloth, 380; Packaging materials, 379; Special fabrics (window shades, rugs, curtains, upholstery), 245; Plastics, 243; Flight clothing, 392; Rubber hose and gasket materials, 395; Canopy materials, 397; Plastic radome materials, 399; Curtain materials (aircraft), 400; Chemical warfare protective materials, 401; Ceramics, 402; Flame proofed cotton fabric, 403.
9. *Primary Ignitions Following Atomic Attack on Urban Targets-Transient Exterior Fuels,* AFSWP–413, F. M. Sauer, et al. (For. Serv.), Jun 53 (U).
10. *Remarks on Estimation of the Number of Fires Due to the Ignition of Transient Exterior Kindling Fuels,* AFSWP–861, F. M. Sauer (For. Serv.), Oct 55 (U).
11. *Relative Protection Against Radiation Burns Provided by Heat-Treated Orlon,* NML 5046–3 Pt–20, Final, W. J. Bates and M. S. Kelly (NML), 13 Aug 52.
12. *Research Report on the Relative Spectral Energy Distribution of the NML Carbon-Arc Source of Intense Thermal Radiation,* AFSWP–1002, W. L. Derksen (NML), 31 Jul 56 (U).
13. *Research Report on Thermal Damage to Cloths as a Function of Time of Exposure, Nuclear Weapon Pulses,* AFSWP–996, J. J. Bates (NML), 1956 (C).

~~CONFIDENTIAL~~

~~WARNING NOTICES~~

~~*Authority for release of this document to a foreign government must be secured from the Assistant Chief of Staff, Intelligence, Headquarters, Department of the Army.*~~

~~When this document is released to a foreign government, it is released subject to the following conditions: This information is furnished with the understanding that it will not be released to another nation without specific approval of the United States of America, Department of the Army; that it will not be used for other than military purposes; that individual or corporation rights originating in the information whether patented or not will be respected; and that the information will be afforded substantially the same degree of security as afforded by the United States of America, Department of the Army.~~

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18 U. S. C., sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~CONFIDENTIAL~~